United States
Deparment of
Agriculture

Forest Service

Northeastern Area
State and Private Forestry

NA–TP–02–05

August 2005

Diameter-Limit Cutting and Silviculture in Northeastern Forests:

A Primer for Landowners, Practitioners, and Policymakers

Acknowledgments

Reviews of an earlier version of this manuscript were provided by John Brissette, MaryAnn Fajvan, and Paul Sendak of the USDA Forest Service, Northeastern Research Station; Philip Hofmeyer and David Ray of the University of Maine; and Daniel Simonds of SGS, Systems and Services Certification. We thank Roger Monthey and Robert Clark of the USDA Forest Service, Northeastern Area State and Private Forestry, for their support.

Federal Recycling Program
Printed on recycled paper

Diameter-Limit Cutting and Silviculture in Northeastern Forests:

A Primer for Landowners, Practitioners, and Policymakers

By Laura S. Kenefic[1] and Ralph D. Nyland[2]

Published by:

USDA Forest Service
Northeastern Area State and Private Forestry
11 Campus Boulevard, Suite 200
Newtown Square, PA 19073

August 2005

www.na.fs.fed.us

[1] Research Forester, USDA Forest Service, Northeastern Research Station, Bradley, ME. Phone: 207-581-2794. Fax: 207-581-4257. E-mail: lkenefic@fs.fed.us.

[2] Distinguished Service Professor, Silviculture, SUNY College of Environmental Science and Forestry, Syracuse, NY. Phone: 315-470-6574. Fax: 315-470-6956. E-mail: rnyland@mailbox.syr.edu.

Table of Contents

Sustainable Forestry

Whether we leave them alone or use them wisely, the forests of northeastern North America are renewable. Trees regenerate naturally, grow and develop to large sizes, and eventually die. They provide critical habitats for plants and animals, clear water and air, recreational opportunities, and an array of other benefits to the people who live in and visit the region.

With appropriate **silviculture**,[1] landowners can sustain their forests indefinitely while using them today for many different purposes (figure 1). That is the essence of sustainable forestry. It means keeping forests healthy, dynamic, and available for future generations. This includes monitoring forest health and other conditions, maintaining appropriate levels of **stocking** and **structure**, enhancing the growth and vigor of desirable species, and **regenerating** new trees and forests when the current ones reach maturity or no longer serve the landowner's needs.

These goals are realized through silviculture, which includes several methods that **tend** the trees growing on a site and regenerate new ones at appropriate times. And because trees of good form and marketable species have value for a host of products that people depend on for daily living, landowners can sell excess and mature trees to generate revenue and pay off their investments in ownership and management (figure 2).

Figure 1.—A managed northern hardwood stand.

[1] All words in boldface are defined in the appendix; see Helms (1998) for more complete definitions.

Figure 2.—Timber harvesting gives landowners the opportunity to alter the condition and density of their forest to serve a variety of objectives and generate revenue in the process.

What Really Happens in the Forest?

Unfortunately, many landowners neither use silviculture nor practice sustainable forestry. Instead they rely on **diameter-limit cutting**, removing large trees and leaving smaller ones. In some cases, only commercially valuable trees are cut. This practice, called **high-grading**, leaves poor-quality stems (including **culls**) and commercially undesirable species.

Neither diameter-limit cutting nor high-grading tends the residual **stand** to reduce crowding or favor the best quality and most vigorous trees for the future. Nor do these practices deliberately regenerate new trees to replace the ones removed by the cutting. As a result, residual stands may have a patchy and irregular mixture of open and crowded areas, short and poorly formed trees, or trees of low value (figure 3).

This creates undesirable conditions within the forest and reduces the potential for producing consistent amounts of **sawtimber** and maintaining other forest values. The situation usually worsens when a second or third diameter-limit cut is applied to the same stand.

Although new trees usually regenerate after a diameter-limit cut, they are not always of desirable species or in sufficient numbers to adequately occupy the site. Unmerchantable trees grow larger but are unlikely to develop into ones of high quality. By contrast, sustainable forestry is characterized by deliberate control of residual stand conditions in order to meet commodity and noncommodity objectives. For example,

FIGURE 3.—Northern conifer stands after a diameter-limit cut (top) and following a silvicultural treatment.

although decayed trees are common in diameter-limit cut stands and are important components of wildlife habitat, the lack of a specific residual structure makes it difficult to predict outcomes for wildlife. Diameter-limit cutting simply removes the biggest trees, liquidating timber assets and trading long-term production potential and other values for immediate financial gain.

KEY CHARACTERISTICS OF NORTHEASTERN FORESTS

Northeastern North America has three basic kinds of forest stands. In **even-aged** stands, the trees all regenerated at about the same time and have similar ages. In **uneven-aged** stands, the trees regenerated periodically over a long period, creating a mixture of young, middle-aged, and older trees (figure 4). **Two-aged** stands commonly have a relatively low-**density overstory** of older trees, with a second **age class** of younger ones growing beneath them. Such stands often form after partial cutting removes most, but not all, of the trees from an even-aged stand. Because of their dissimilar conditions, diameter-limit cutting affects each of these three types of stands in a unique way.

Even-Aged Stands

Although the trees in even-aged stands regenerate at about the same time and are similar in age, they do not grow at the same rate. Some species have more rapid growth than others. Even among trees of the same species, those best adapted to the site grow the tallest and have the largest diameters, while others develop more slowly and remain somewhat shorter. As a result, even-aged stands usually contain trees of varying diameters with some differences in height. In stands composed of species with distinctly different rates of height growth, the faster growing species may overtop the others. These **stratified mixed-species**

stands have distinct **canopy** layers, but they differ from two-aged stands in that both the small and large trees are the same age.

In even-aged stands that contain species with similar growth characteristics, foresters use differences in height to assign trees to one of four crown classes (figure 5). Dominant trees are the tallest and have grown into the uppermost crown positions. They receive the most light at the top and around the upper branches, and have the largest crowns and trunk diameters. Codominant trees make up the main part of the canopy. Though somewhat shorter than the dominants, they receive good light at the top and have moderate-size crowns and trunk diameters. Intermediate trees barely reach into the bottom of the main canopy and usually grow in the shade of taller trees. They have short, narrow crowns and relatively small diameters. Overtopped trees grow beneath the upper canopy and receive no direct sunlight. They grow slowly and have the smallest diameters. A similar height differentiation can occur within each canopy layer in stratified mixed-species stands, though the primary distinction in that case is between rapidly and slower growing species.

In even-aged stands, tree diameter generally reflects crown position and growth rate. As indicated in table 1, Nyland and others (1993) found that the 15-year post-**thinning** diameter growth of dominant trees was 1.5 times greater than that of codominants, 2.2 times greater than that of intermediates, and 4.3 times greater than that of overtopped trees. Marquis (1991) reported differences of even greater magnitude for intermediate and overtopped trees in cherry-maple forests, and the disparity of growth rates increased as the stands matured.

These findings highlight a critical outcome from diameter-limit cutting in even-aged stands. Even if a landowner released

Figure 4.—Examples of even-aged (top) and uneven aged northern conifer stands.

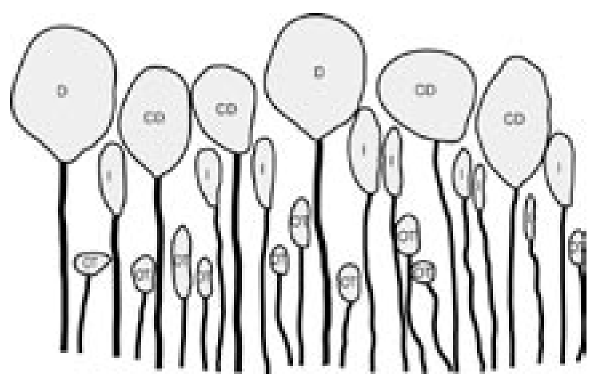

Figure 5.—In even-aged stands, dominant and codominant trees are the tallest, have the largest diameters, and are the best candidates for future growth and development. Crown class tells much about a tree's position in the canopy, exposure to light, and crown size. It also indicates how well trees grow, as well as their diameter relative to nearby trees.

Note: D = dominant, CD = codominant, I = intermediate, O = overtopped.

TABLE 1.—Fifteen-year post-thinning diameter growth of sugar maple trees in different initial crown positions (Nyland and others 1993).

Crown position	15-year total	Annual
	Diameter growth (inches)	
Dominant	2.98	0.20
Codominant	1.95	0.13
Intermediate	1.36	0.09
Overtopped	0.69	0.05

intermediate and overtopped trees by cutting larger trees nearby, the small residuals would not grow as well as their larger neighbors could have. Cutting large trees from even-aged stands and keeping small ones often leaves stands of lower vigor and growth rates, and less volume production (figure 6). By contrast, appropriately applied thinning frees crowns of the best trees and controls the density and spacing of the residuals. It exposes their crowns to more sunlight but maintains sufficient numbers for utilization of site resources and acceptable levels of future volume growth. In the long run, thinning can increase the volume yields from an even-aged stand as well as long-term income for the landowner.

FIGURE 6.—Differences in quality and stocking among residual trees after diameter-limit cutting (top) and thinning in even-aged stands.

The situation is somewhat different in stratified mixed-species stands. Trees in the upper **stratum** are often fairly widely spaced, so thinning may not enhance their growth. Some trees of poor condition might be cut to upgrade the stand and to increase the amount of light reaching shorter trees. This treatment could also reduce crowding within the lower stratum, concentrating growth potential on the best trees and opening space around their crowns. By contrast, diameter-limit cutting likely would remove most or all of the upper stratum, reducing tree species diversity and eliminating the seed source for some species. This has implications for later attempts to regenerate the stand. In addition, diameter-limit cutting would not necessarily reduce crowding among the residuals (formerly the lower stratum) nor improve stand quality by favoring the best trees among them.

Uneven-Aged Stands

Conditions differ in uneven-aged stands, which have at least three distinct age classes of trees that regenerated over a range of time, usually after periodic cutting or natural disturbance created scattered openings in the upper canopy. Such stands usually have upper, middle, and lower canopy layers representing different age classes. Within each age class, some trees have larger crowns, grow more rapidly, and have better quality than the others. When released by cutting, those better quality trees can grow even more rapidly.

The primary silviculture for uneven-aged stands is called the **selection system**. To accommodate the differences in tree age, each **selection cutting** removes mature trees to regenerate new ones as replacements, and tends immature age classes by opening growing space around trees of the best growth potential and quality (figure 7). Selection cutting regulates the number of trees left in each age or size class to control the distribution of growing space among **cohorts**. This combination of practices reduces crowding around the best trees, stimulates their growth, and controls mortality. Landowners can sell the harvested trees to pay the costs of ownership and management.

By contrast, diameter-limit cutting in uneven-aged stands removes only the largest trees, often including most of the sawtimber. This usually eliminates the older age classes entirely, but does not intentionally regulate spacing between the younger residuals, nor remove poor trees to favor better ones. Overall stand quality is unlikely to improve in the long term.

Two-Aged Stands

Silviculture for two-aged stands includes a treatment that removes most of the overstory of an even-aged stand, leaving widely spaced trees and triggering the regeneration of a new age class in the understory. This new cohort is then **tended** to remove excess numbers of stems, leaving the best for future growth and improving spacing. Additional thinning later on may continue to promote growth and development. This combination of treatments constitutes a viable silvicultural approach for creating and maintaining two-aged, two-storied stands.

To the casual observer, cutting old trees in a two-aged stand resembles diameter-limit cutting. However, two-aged silviculture retains good-quality trees from the older age class and deliberately regenerates a new cohort of desired species beneath the residuals. Tending is applied to stimulate growth and development of the younger age class, and overall stand quality is improved. This attention to residual stand condition, retention of quality residuals, and controlled regeneration distinguish two-aged silviculture from diameter-limit cutting.

The Evidence

The first diameter-limit cut in a stand often removes a great volume of sawtimber, providing the landowner with considerable income. But such harvests usually leave only small trees, particularly when a low

Figure 7.—Post-cut conditions in diameter-limit (top) and selection-system stands.

diameter limit is used (figure 8). Silviculture focuses on the condition of the residual stand by controlling stocking of the residual trees and regenerating a new age class when appropriate. Silviculture also can be used to generate dependable amounts of quality sawtimber volume over the long term. Nevertheless, the immediate financial gains from diameter-limit cutting often motivate landowners to ask, "Why shouldn't I take out the best trees now, if that will give me the most money today?"

Until recently, foresters had limited information about the long-term effects of diameter-limit cutting. But recent data from experiments comparing different cutting strategies in northern conifer and northern hardwood forests reveal important differences in the potential for timber production and sustainability between diameter-limit cutting and silviculture.

Diameter-Limit Cutting in Even-Aged Stands

Information on diameter-limit cutting is limited for even-aged stands. Yet, knowing the growth rates for trees of different diameters has allowed researchers to simulate the effects of diameter-limit cutting and thinning. Findings indicate that the dissimilar outcomes of these practices are due to differences in residual-tree density, growth, and development, and the volume and value of sawtimber products harvested over time. Landowners will see the greatest differences between these practices when diameter-limit cutting is repeatedly applied to the same stand.

In a simulation study, Nyland and others (1993) found that an even-aged northern hardwood stand supported a **commercial thinning** at about 70 years of age (figure 9). The treatment removed about 12 **cords** of pulpwood and 800 **board feet** of sawlogs per acre. It favored the best trees, removed competing ones, and controlled stocking to optimize site utilization. Sawtimber volume increased sufficiently to allow additional commercial thinnings at 15-year intervals thereafter, and each successive entry provided greater amounts of board-foot volume. By the time the stand reached 113 years of age, the combined thinnings plus the final **overstory removal** yielded a cumulative volume of about 24,000 board feet per acre (table 2). Eighty-five percent came from trees at least 16 inches in **diameter at breast height** (d.b.h.). Trees of that size often have the highest value because they yield higher proportions of top grade lumber.

By contrast, other simulations by Nyland and others (1993) showed that repeated diameter-limit cutting on a 15-year interval, taking out all trees at least 12 inches in

FIGURE 8.—A first diameter-limit cut often removes the best trees and high-value species (left), leaving only smaller, poor-quality trees for future harvests.

diameter at each entry, yielded only 70 percent as much volume as the thinnings. Only 10 percent of the cut was from trees larger than 16 inches in diameter. The thinned stand had trees as large as 25 inches in diameter after 113 years, but the diameter-limit stand only had trees smaller than 16 inches. Repeated diameter-limit cutting throughout the 113-year period provided one-half as much revenue and a lower return on investment in management than the thinned stand.

FIGURE 9.—A 70-year-old, even-aged northern hardwood stand will support operational thinning that regulates spacing and density, and concentrates the growth on high-quality dominant and codominant trees.

Diameter-Limit Cutting in Uneven-Aged Stands

In the early 1950s, the USDA Forest Service, Northeastern Research Station initiated one of the longest comparisons of silviculture and diameter-limit cutting in uneven-aged northern conifer stands on the Penobscot Experimental Forest in Maine (Sendak and others 2003). Treatments included fixed diameter-limit cutting and the selection system. Diameter-limit cuts were applied every 20 years using species-specific limits ranging from 5 to 11 inches d.b.h. The cuttings removed all merchantable trees larger than those limits, and no smaller trees were harvested. In the selection stands, unmerchantable and poor vigor trees as well as undesirable species were removed every 20 years. The selection system maintained a broad range of tree sizes and ages, and established and released regeneration. To date, both treatments have been applied three times.

Recently summarized data show that repeated diameter-limit cutting left the stands with fewer large trees, less sawtimber volume and growth, and one-half as much regeneration as selection cutting (Kenefic and others 2005). In fact, diameter-limit cut stands had virtually no medium to large sawtimber after the first entry, while the amount of sawtimber increased steadily in the selection stands (figure 10). After three entries, cull (unmerchantable) timber accounted for less than 1 percent of the volume in the selection stands but more than 25 percent of the volume in the diameter-limit stands. In the latter case, logging left cull trees regardless of their diameter, while selection cutting removed culls to upgrade stand quality. Proportions of valuable species such as spruce and birch increased in the selection stands, but not in the diameter-limit stands.

Although overall harvest value was greater in the diameter-limit stands due to early removals of the best timber, the value of the residual trees after three treatments was less than one-sixth that of the selection stands (Kenefic and others 2005). Further, diameter-limit cutting in uneven-aged stands left them more like similarly treated even-aged stands than like uneven-aged stands

TABLE 2.—Differences in diameter distributions or yields over a 113-year **rotation** (Nyland and others 1993).

Yield	Crown thinning	12-inch diameter limit
Cumulative board feet per acre	23,739	16,520
Percentage of trees at least 16 inches in d.b.h.	86	10

managed by the selection system (Kenefic and others 2004). Simulations suggested that the diameter-limit stands would not have sufficient sawtimber for another harvest of equal volume after the next 20 years (the length of time between previous harvests). Over the long term, reduced volume and value offset greater first-cut revenue from the diameter-limit stands.

A simulation experiment using data from sugar maple stands in New York showed similar results (Nyland 2005). That study compared volumes and revenues produced over a century in three selection stands with repeated diameter-limit cutting that removed all trees more than 14 or 16 inches in diameter (table 3). The diameter-limit cuts did not include any tending of the smaller size classes. In the first entry, the cut took out more volume and provided higher revenue, but over a century-long period of management, diameter-limit cutting yielded 1.2 times less volume and value than the selection system. The latter yielded more consistent harvest volumes over time and allowed repeated cutting treatments at 15-year intervals. The diameter-limit stands did not regrow sufficient volume to support a commercial harvest more frequently than every 20 to 25 years, and the amounts available differed considerably from one entry to the next. Further, diameter-limit stands had only small sawtimber trees to remove after the first entry. Overall, diameter-limit cutting resulted in less volume, less value, and less consistency of volume yield through time. It also provided a lower return on investment compared to uneven-aged northern hardwood stands managed by the selection system. The similarity of these results with those from the northern conifer study is compelling and suggests that the findings of these two experiments are relevant to diameter-limit cutting at the regional scale.

Potential Genetic Effects of Diameter-Limit Cutting

Many tree species in northeastern forests live for more than 100 years. Some take decades to reach a merchantable size or to begin producing ample amounts of viable seed. Trees left after harvesting often provide seed for new regeneration. So when landowners leave trees with poor growth and other undesirable characteristics, they might adversely affect the future forest if

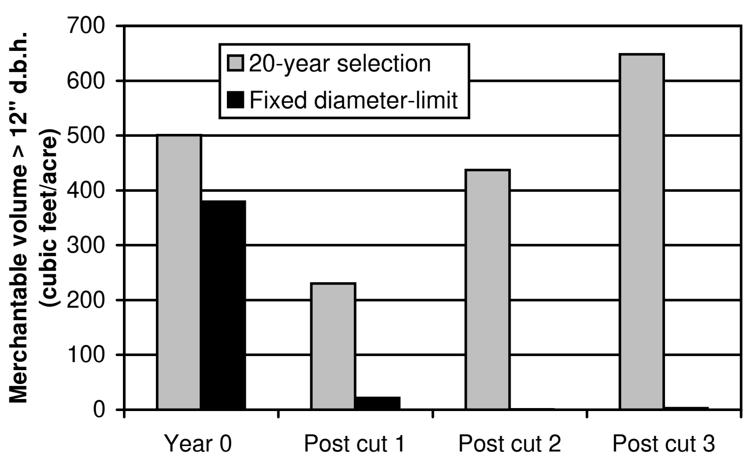

FIGURE 10.—Medium to large sawtimber volume in diameter-limit and selection-sytem stands on the Penobscot Experimental Forest in Maine.

TABLE 3.—Annualized values for total production for simulated diameter-limit and selection-system cutting through a 90- to 100-year period (based upon actual residual diameter distributions in real uneven-aged stands).

Stand	Number of years	Cutting interval	Annualized production[a]
		Years	Board feet per acre
		Diameter-limit cutting	
Stand 4, (14-inch diameter)	100	20	310
Stand 6, (16-inch diameter)	100	25	195
Stand 7, (16-inch diameter)	90	30	205
		Average	237
		CV[b]	25%
		Selection system cutting	
Sel A	90	15	262
Sel B	90	15	263
Sel C	90	15	294
		Average	273
		CV	7%

[a] Includes harvested volumes plus what is left standing after last cutting in a stand. Annualized values obtained by dividing total volume production for a stand by length of management period.

[b] Coefficient of variation (CV) indicates variability in annual volume production among three diameter-limit and selection-system stands. It is expressed as percentage of average value. A low CV indicates more consistency in annual volume production through time.

an **understory** of desirable young trees is not already established. In stands with well-established **advance regeneration**, overstory removal frees the new cohort for continued growth and development.

Some foresters believe that diameter-limit cutting affects the genetic potential of a stand by removing the best trees and leaving the poorest. They believe that the larger, faster growing trees removed from an age class are genetically superior, and that cutting only those trees degrades growth potential. If so, this might reduce the genetic quality of the seed source that remains as well as the quality of the trees that later regenerate on the site. Such concerns were reinforced by a study of eastern hemlock on the Penobscot Experimental Forest that revealed differences in genetic characteristics among trees in diameter-limit and selection stands (Hawley and others 2005). Trees in the diameter-limit stands had more rare alleles (genes) that were associated with small and poorly formed trees. This suggests that diameter-limit cutting reduced productivity and short-term fitness of the stands.

Sokol and others (2004) also explored the genetic implications of diameter-limit cutting by examining residual red spruce at least 100 years old in uneven-aged stands on the Penobscot Experiment Forest. In diameter-limit stands, trees of that age class had smaller diameters and had grown more slowly than those of the same age in the selection stands. Their findings suggest that diameter-limit cutting had removed the best of the cohort, leaving trees with a more limited growth potential. These findings, consistent with the patterns expressed in table 1, support the conclusion that harvesting the largest trees from an age class removes the ones with the best growth potential. The effect is somewhat mitigated in uneven-aged stands because diameter-limit cutting does not affect the younger cohorts, which still have trees with potential for good growth and development. However, if repeated diameter-limit cutting continually removes the best trees of the older age classes, seed for new seedlings might come from the remaining poor-quality trees.

Can Landowners Rehabilitate Heavily Cutover Stands?

Diameter-limit cutting has affected thousands of acres across northeastern North America (Nyland 1992), challenging managers to rehabilitate the most heavily cutover stands. Yet alternatives remain largely unexplored. One simulation study of even-aged northern hardwoods found that landowners had few options after only two diameter-limit harvests (Maguire and others 2005). Alternatives for improving stand conditions through commercial logging were limited by low stocking, low value, and an abundance of undesirable or nonmerchantable species. Such conditions also apply to diameter-limit cut uneven-aged stands (Nyland 2003a). Following diameter-limit cutting, stands of both kinds contain mostly saplings, poles, and other trees of low value. Inadequate stocking compromises growth potential and could make continued management financially unattractive.

In order to rehabilitate degraded stands, landowners need to improve stand quality and value, thin dense clumps of residual trees, and regenerate new trees to fill open spaces. The number and spatial distribution of acceptable trees determines a stand's potential. In many cases, stand replacement may be the best alternative.

For stands with some good trees, but not enough for traditional management, rehabilitation might:

1. Remove the poorest trees, leaving a few widely spaced ones with the best characteristics for growth and seed dispersion;
2. Release desirable advance regeneration and promote its development; and
3. Increase the amount of desirable regeneration where an assessment indicates a need.

This approach would leave a low-density stand of widely spaced trees and convert an even-aged stand to one with two distinct age classes (two-aged). It would maintain multiple age classes in an uneven-aged stand, but at a low density.

In more extreme cases, with only a low stocking of mostly low-quality trees of little value, landowners could:

1. Remove or kill all the overstory trees;
2. Assess the stocking of advance regeneration to determine if it includes adequate numbers of desirable species; and
3. Establish new regeneration if presently inadequate, perhaps by planting or seeding.

This strategy essentially regenerates a new even-aged stand that later can be treated with traditional even- or two-age silviculture.

Either rehabilitation option would likely require some investment and might defer revenue. The cutover stands must be restocked with new trees, and management should involve methods to reduce interfering understory vegetation that would impair seedling survival and development. The cost of this work may discourage many owners. Yet for stands with adequate advance regeneration to eventually restock open areas, or sufficient young trees of good promise to occupy the site, simply waiting may suffice. This requires no immediate investment in rehabilitation work but does delay the time until a stand reaches its productive potential and provides a good income to the landowner. Also, poor-quality trees that remain after diameter-limit cutting just get larger, and stands dominated by them are unlikely to improve over time. In those cases, waiting will not help.

Each case requires a unique solution depending on residual conditions and the landowner's objectives (figure 11). The approach will differ for stands with trees of multiple age classes compared to stands with trees of a single age class. Even so, the following rules of thumb can guide planning for rehabilitation (Nyland 2003a):

1. Look for trees with reasonably well-developed and balanced crowns (having live branches on all sides), good stem form, marketable quality, and potential to produce seed. For reserve trees, at least 20 to 25 percent of the main stem should have live branches.
2. Keep sufficient numbers of trees for future management and cut the rest.
3. For uneven-aged stands, retain good trees of different sizes interspersed throughout.
4. Remove enough volume for a commercial harvesting operation and to remove unacceptable trees.
5. Leave uniform spacing independent of the number of trees left for the future.
6. Deliberately establish a new age class unless the overstory trees will fully occupy the site as they develop.
7. Reduce interfering vegetation to ensure successful regeneration.

In other cases, landowner objectives might encourage stand replacement by cutting all remaining trees and simultaneously establishing new seedlings across the site, even by artificial means. Most importantly, landowners who have not yet done diameter-limit cutting should use silviculture, which will provide better options and more desirable outcomes in the long term.

Implications

Diameter-limit cutting fails as a long-term strategy for sustainable forestry. It neither improves the quality and value of trees in a stand nor controls the stocking for optimum long-term production of sawtimber and for other values. Diameter-limit cutting does not provide consistency in long-term yields, nor does it deliberately enhance hydrologic or other ecologic conditions. Further, the appearance of diameter-limit stands may detract from recreational potential. In short, diameter-limit cutting shows little regard for the future and does not optimize long-term values for a landowner.


Figure 11.—Rehabilitation treatments must leave the best of the residual trees, often at a wide spacing.

Landowners who want to manage their forests to sustain desired values over the long term will benefit from silviculture. One alternative to diameter-limit cutting might include deliberately regenerating suitable even-aged stands at younger ages than normal, using appropriate silviculture to ensure prompt occupancy of the site by new trees of desirable species. The process might start with a partial cutting in stands lacking abundant advance seedling regeneration, returning to completely remove the remaining overstory trees when the new age class reaches a suitable size. This is called the **shelterwood** method. The first cut would reduce the best of the older age class to a wider spacing than normally used with thinning. The residuals would provide seed for the new age class as well as partial shade to help protect the young trees. Some landowners might also need to control undesirable vegetation that would interfere with development of the new trees.

As another alternative for even-aged stands, landowners might use a series of patch cuttings to regenerate a new age class. Each entry might remove the older trees in patches covering an area equal to one-third to one-half of the stand, leaving the intervening space untended. Each cutting would create openings having a width similar to the height of adjacent residual trees, which would provide seed and partial shade. When the new trees in the openings reach a suitable size to grow well in full sunlight, a second series of dispersed patches could be created in the same stand. After two or three entries, the overstory would be removed and young trees would cover the entire stand area.

With stratified mixed-species stands, landowners could use a different approach. Usually, the upper canopy includes trees that grow best in full sunlight and reach merchantable sizes sooner. Those in the lower stratum can withstand some shading but grow more slowly. These trees generally have smaller diameters and take longer to reach merchantable size. In stratified mixed-species stands, landowners might take out most of the overstory species when the trees reach a stage of development that recommend their removal, but retain sufficient numbers of the best and most vigorous upper stratum trees to ensure adequate seed dispersal when the lower stratum reaches merchantable size. The cutting could also thin the lower stratum to promote its growth and development. Landowners would receive revenue from harvesting most of the upper stratum species, and from thinning the remainder of the stand. They would retain a viable seed source for all component species, providing opportunities to regenerate a diverse new community of trees.

Landowners might also consider converting even-aged stands to a two-aged condition. In stands lacking abundant advance seedling regeneration, a partial overstory removal could be applied as described earlier. After desirable regeneration formed in the understory, most of the older trees could be removed, leaving widely spaced residuals of the largest sizes and highest quality. In stands already having an adequate understory of desirable seedlings or young trees, all but choice overstory trees at a wide spacing could be removed. This would release the understory and encourage its growth and development. In both cases, the older reserve trees could be left to an extended age, forming a low-density overstory above the new age class.

Landowners could also convert an even-aged stand to an uneven-aged condition. This would require a long series of partial cuts. Nyland (2002) suggested that the first cut remove the small trees, leaving only dominants and codominants at uniform spacing. Each additional entry would remove more of the older trees, maintaining an appropriate spacing between residuals and setting the stage for regeneration to fill the newly opened spaces. Seymour (2004) suggests a similar approach for northern conifers, but recommends the creation of discrete gaps for regeneration establishment over multiple entries. In either case, the stands eventually would have multiple age classes and could be managed with uneven-age silviculture.

In uneven-aged stands, a landowner might elect to keep fewer age classes and cut more heavily at each entry (Nyland 2003b), leaving a stand of trees of different ages and sizes, including some as large as 16 inches in diameter. Each cutting would tend the residual age classes, leaving the best trees and improving the spacing between them. By periodically cutting some of the large trees to create small gaps in the upper canopy, landowners could improve the chances for new seedlings to become established in the openings. But when they decide to cut more heavily and leave a low residual stocking, landowners must wait longer for growth to add sufficient volume for another selection cutting in the stand. Even so, this approach for uneven-aged stands may prove more financially attractive over the long term than repeated diameter-limit cutting.

Any of these strategies would give landowners a viable alternative to diameter-limit cutting while providing income in the short term. The best choice depends on the landowner's interests and the condition of the stand (figure 12). Good planning usually will uncover a strategy that avoids the long-term pitfalls of diameter-limit cutting, while still providing many landowner benefits. Deliberate efforts are needed to monitor conditions in the forest, maintain appropriate levels of stocking, enhance the growth and vigor of desirable species, and regenerate new trees and new forests when the current ones mature or no longer serve the landowner's needs.

FIGURE 12.—Landowners' values vary, but often include protecting the forest for future generations.

Literature Cited

Hawley, G.J; Schaberg, P.G.; DeHayes, D.H.; Brissette, J.C. 2005. Silviculture alters the genetic structure of an eastern hemlock forest in Maine. Canadian Journal of Forest Research. 35: 143–150.

Helms, J.A. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 210 p.

Kenefic, L.S.; Brissette, J.C.; Sendak, P.E. 2004. The effects of alternative diameter-limit cutting treatments: some findings from a long-term northern conifer experiment. In: Ward, J.S.; Twery, M.J., eds. Forestry across borders: proceedings of the New England Society of American Foresters 84th winter meeting. Gen. Tech. Rep. NE–314. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 22–24.

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: 78–84.

Maguire, M.P.; Kenefic, L.S.; Wilson, J.; Nyland, R.D. 2005. Simulating rehabilitation treatments in northern hardwood stands following diameter-limit cutting. In: Kenefic, L.S.; Twery, M.J., eds. Changing forests—challenging times: proceedings of the New England Society of American Foresters 85th winter meeting. Gen. Tech. Rep. NE–325. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 60. Abstract.

Marquis, D.A. 1991. Independent effects and interactions of stand diameter, tree diameter, crown class, and age on tree growth in mixed-species even-aged hardwood stands. In: McCormick, L.H.; Gottshalk, K.W., eds. Proceedings of the eighth central hardwood forest conference. Gen. Tech. Rep. NE–148. Radnor [Newtown Square], PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 442–458.

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

Nyland, R.D. 2002. Silviculture: concepts and applications. 2nd ed. New York: McGraw-Hill Book Co. 704 p.

Nyland, R.D. 2003a. Even- to uneven-aged: the challenges of conversion. Forest Ecology and Management. 172: 291–300.

Nyland, R.D. 2003b. Rehabilitating stands after diameter-limit cutting. In: Tolerant hardwood management conference proceedings; 2003 May 8; Edmundston, NB. [CD-ROM]. Edmundston, NB: Universite de Moncton.

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: 111–116.

Nyland, R.D.; Alban, L.M.; Nissen, R.L., Jr. 1993. Greed or sustention: silviculture or not. In: Briggs, R.D.; Krohn, W.B., eds. Nurturing the northeastern forest: proceedings of a joint meeting of the New England Society of American Foresters and Maine Chapter of the Wildlife Society. CFRU Inf. Rep. 33; Misc. Rep. 382; SAF Publ. No. 93–05. Orono, ME: University of Maine: 37–52.

Sendak, P.E.; Brissette, J.C.; Frank, R.M. 2003. Silviculture affects composition, growth, and yield in mixed northern conifers: 40-year results from the Penobscot Experimental Forest. Canadian Journal of Forest Research. 33: 2116–2128.

Seymour, R.S. 2004. Integrating natural disturbance parameters into conventional silvicultural systems: experience from the Acadian Forest of northeastern North America. In: Peterson, C.E; Maguire, D.A., eds. Balancing ecosystem values—innovative experiments in sustainable forestry: proceedings of the IUFRO conference. 2004 August 16–20. Gen. Tech. Rep. PNW–635. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 41–48.

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.

Appendix—Definitions of Terms Used in This Report

advance regeneration—Tree seedlings or small saplings that develop in the understory prior to the removal of the overstory.

age class—Trees that have the same or similar age, also known as a cohort. All trees in an age class became established around the same time.

board foot—A piece of lumber 1 foot wide, 1 foot long, and 1 inch thick. Estimates of board-foot volume for standing trees and logs account for the amount of wood that goes into sawdust and other unused parts of a tree or log.

canopy—The layer of foliage formed by the crowns of trees in a stand. For stands with trees of different heights, foresters often distinguish among the upper, middle, and lower canopy layers. These represent foliage on tall, medium, and short trees. The uppermost layers are called the overstory.

cohort—See **age class**.

commercial thinning—A thinning applied to a stand with trees of sufficient volume and quality to produce merchantable material at least equal to the cost of harvesting. A precommercial thinning is one applied to a stand in which the trees are too small to be marketed.

cord—An 8-foot-long pile of wood stacked 4 feet high and composed of 4-foot-long pieces.

cull—Unmerchantable trees, usually the result of extensive decay, crookedness, or stem qualities that preclude their usefulness for the intended products.

d.b.h. (diameter at breast height)—The diameter of the stem of a tree measured at breast height (usually 4.5 feet above the ground). This term is commonly used by foresters to describe tree size.

density—The number of trees per unit area, often implying the degree of crowding among trees. Foresters often express stocking and density as relative measures by comparing the current numbers of trees to that considered optimal for management.

diameter-limit cutting—Removing all trees larger than a selected size, usually the minimum sawlog diameter. Also called fixed diameter-limit cutting.

even-aged—A stand having one age class of trees.

high-grading—Cutting only the commercially valuable trees from a stand, leaving cull, poor quality trees, and those of low-value species.

overstory—See **canopy**.

overstory removal—Cutting trees in the overstory to release shorter ones or advance regeneration.

regenerating—Establishing a new age class. Silviculture does this in a way that controls the species composition, seedling density, and other characteristics consistent with the landowner's objectives.

rotation—The period of time from establishment of an even-aged stand until its maturity.

sawtimber—Generally trees at least 12 inches in diameter. Poletimber usually is 6 to 11 inches in diameter, and saplings are 1 to 5 inches in diameter. There is some variation by forest type.

selection cutting/selection system—The silvicultural system used to regenerate and maintain uneven-aged stands. Selection cuttings are used to remove individual or small groups of mature trees to regenerate a new cohort, as well as to thin the immature age classes to promote their growth and improve their quality.

shelterwood—A method used to regenerate even- or two-aged stands. Overstory density is reduced sufficiently to allow regeneration in the partially shaded understory. Removal of the residual trees after the regeneration period results in an even-aged stand, while retention of the residuals creates a two-aged stand.

silviculture—Tending and regenerating forest stands to realize sought after benefits and sustain them over time.

stand—An area of trees with a common set of conditions (e.g., based on age, density, species composition, or other features) that allow a single management treatment throughout.

stocking—The numbers of trees and amount of growing space used by those trees relative to the amount available. Low stocking implies insufficient numbers of trees to produce volume at the fullest level.

stratified mixed-species stand—An even-aged stand composed of species with different height growth rates, resulting in the development of distinct canopy layers.

stratum—A distinct layer of foliage that comprises the upper, middle, or lower canopy layer.

structure—The horizontal and vertical arrangement of trees and other vegetation having different sizes, resulting in different degrees of canopy layering, tree heights, and diameters within a stand.

tending—Any treatment designed to enhance the growth, composition, health, and quality of trees in a forest stand.

thinning—Reducing the density of trees in a stand primarily to improve the growth and condition of residual trees and prevent mortality. This term describes treatments in immature even-aged stands that do not attempt to establish regeneration.

two-aged—A stand having two age classes of trees with distinctly different ages.

understory—The lower layer of vegetation in a stand, which may include short trees, shrubs, and herbaceous plants.

uneven-aged—A stand having three or more age classes of trees with distinctly different ages.