Overview of USDA Forest Service Research on Diameter-Limit Cutting in Northern Conifers

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Introduction

Partial cutting has become prevalent in the Northeast in recent years in response to public dissatisfaction with even-age regeneration methods and concerns about retaining trees for biodiversity conservation. Removals based on diameter limits are common. *Diameter-limit cutting* has been defined as the removal of trees above a specified size threshold (Helms 1998), usually without tending the smaller size classes (Kenefic and Nyland 2005). In practice, unmerchantable timber is commonly left, resulting in high-grading, i.e., taking only the best trees from a stand. Because diameter-limit cutting is widespread, it is important to explore long-term implications for sustainability. Experimental applications of diameter-limit cutting, though rare, provide compelling data about treatment effects. The Penobscot Experimental Forest (PEF) in Maine is the site of one such experiment.

Penobscot Experimental Forest

The 4,000-acre PEF is located in the towns of Bradley and Eddington in east-central Maine. The forest was purchased by nine industrial and land-holding companies and leased to the USDA Forest Service in 1950 for a long-term experiment in silviculture. The first experimental treatment was applied in 1952. Although the property was transferred to the University of Maine in 1994, the Northeastern Research Station retains control of the experiment and continues the study today. The experiment has yielded more than 50 years of data on northern conifer silviculture and exploitative treatments.

The PEF is located in the Acadian Forest. An ecotone between the eastern broadleaf and boreal forests, the Forest is characterized by species and structural diversity. Common species include spruce (*Picea* spp.), balsam fir (*Abies balsamea* (L.) Mill.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), northern white-cedar (*Thuja occidentalis* L.), eastern white pine (*Pinus strobus* L.), and hardwoods such as the maple (*Acer* spp.), birch (*Betula* spp.), and aspen (*Populus* spp.).

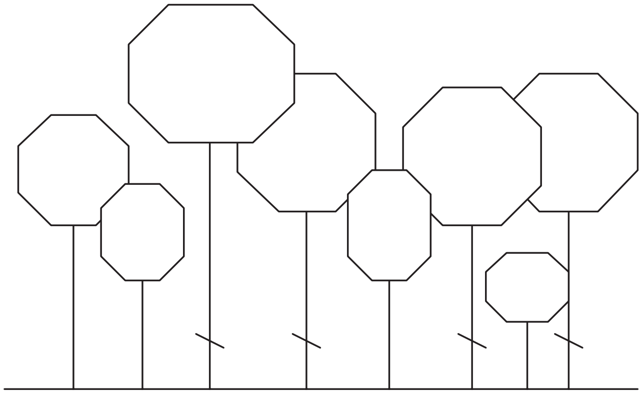

Figure 1.—Trees differentiate into crown classes in even-aged stands of single species. Hash markets indicate trees removed in diameter-limit cutting.

Stand Development and Structure

Before addressing the specifics of the PEF study, it is important to review basic principles of stand development as they are relevant to our findings. In even-aged stands of single species, different height-growth rates result from genetics, microsite, or vigor, causing trees to differentiate into crown classes (Fig. 1). These classes (dominant, codominant, intermediate, and overtopped) indicate potential for future growth. For example, one would not expect an overtopped tree to grow as well as a dominant even if released (Marquis 1991; Nyland et al. 1993). The effect of diameter-limit cutting in stands of this type is easy to grasp: the best growing stock is removed.

Even-aged stands of mixed species can form a more complicated structure. Even though all of the trees are the same age, different species have different growth rates. Faster growing, shade-intolerant species form upper layers or strata, while slower growing, more shade-tolerant species form lower layers (Fig. 2). Within each layer, trees differentiate into crown classes indicative of their growth potential. In these stratified mixed-species

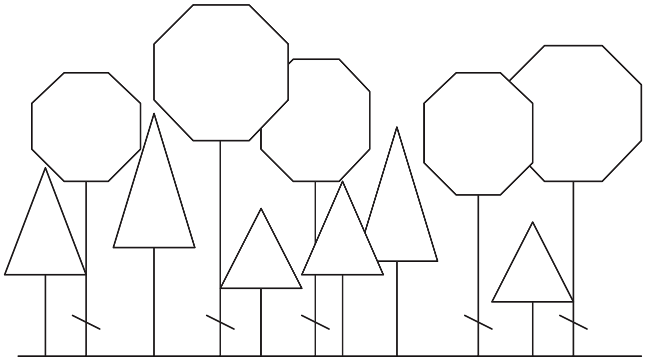

Figure 2.—Mixed-species, even-aged stands have a stratified structure, with crown classes occurring within individual layers. Hash markets indicate trees removed in diameter-limit cutting.

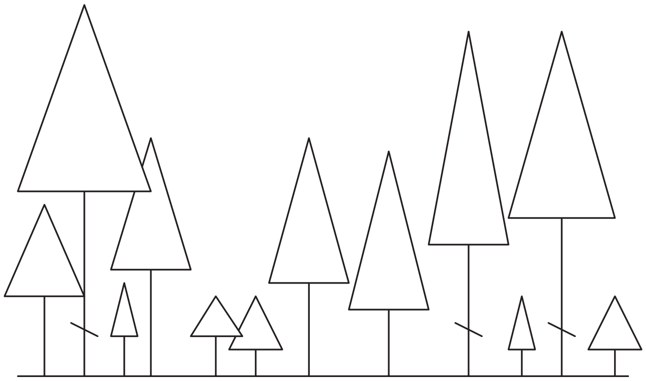

Figure 3.—Multi-aged stands of a single species have strata composed of different age classes, with differentiation occurring within each layer. Hash markets indicate trees removed in diameter-limit cutting.

stands, diameter-limit cutting might remove the better trees of the upper stratum species or the entire upper stratum, resulting in simplification of species diversity.

Multi-aged (uneven-aged) stands are different. In this case, a single species stand has different layers (strata) composed of different age classes (Fig. 3). There are crown classes within each age class. The effect of diameter-limit cutting is more complex. Within age classes, diameter-limit cutting might remove the most vigorous trees but vigorous younger trees remain in the stand.

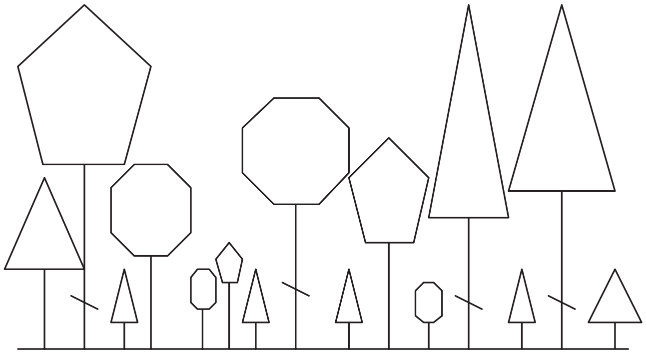

Figure 4.—Mixed-species, multi-aged stands have a complex structure. Different age classes and species form multiple strata, with differentiation into crown classes within each. Hash markets indicate trees removed in diameter-limit cutting.

A more complicated dynamic is found in stratified mixed-species, multi-aged stands, which are common in the northern conifer forest of the Acadian region. Such stands often contain mid- to shade-tolerant species that form a complex structure in which strata are composed of both different age classes and different species (Fig. 4). Individual tree species are found in many canopy layers and age classes; there still are crown classes within strata. Within an age class, the fastest growing species, or the most vigorous trees, might be removed by diameter-limit cutting. Removals of trees from lower strata might include slow-growing trees from older age classes but also the fastest growing trees from younger age classes. This structure, which is found in several PEF stands, limits our ability to accurately predict the effect of diameter-limit cutting.

The PEF Experiment

The long-term silviculture experiment on the PEF includes 10 treatments, each applied to two stand replicates averaging 20 acres in size. The treatment stands were designated as geometric compartments (management units) without consideration of natural stand boundaries. Within-replicate and within-treatment variability are high for most measurement variables (Brissette 1996; Kenefic et al. 2005a). Treatments include even-age (two- and three-stage shelterwood with and without precommercial and commercial thinning) and uneven-age (5-, 10- and 20-year selection) systems, as well as exploitative (removal driven) practices such as commercial clearcutting, i.e., unregulated harvest, and fixed (inflexible) and modified (flexible) diameter-limit cutting (see Sendak et al. 2003).

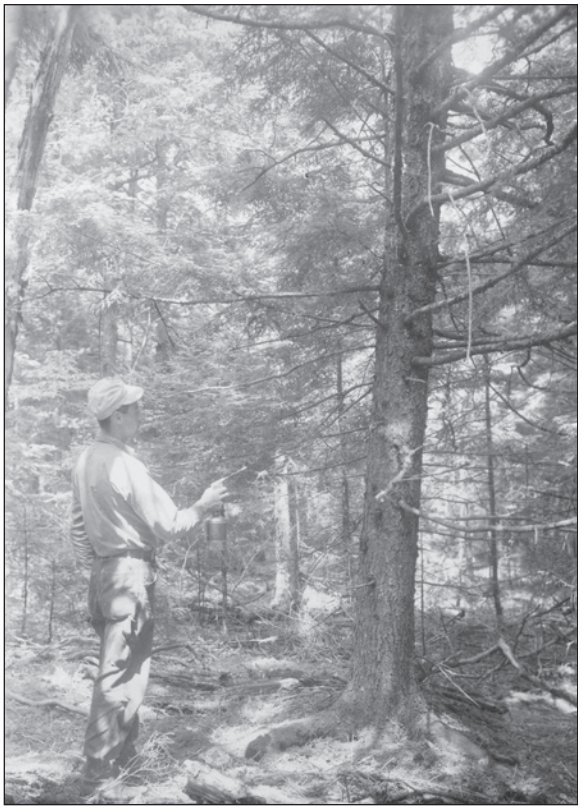

Figure 5.—Pretreatment photos from the 1950s suggest that the PEF was a mixed-species, conifer-dominated forest with irregular stand structures.

Data are collected on a permanent plot network consisting of nested 1/5-, 1/20-, and 1/50-acre plots, covering approximately 15 percent of the treatment area. All trees ≥ 0.5, 2.5, and 4.5 inches in diameter at breast height (dbh, 4.5 feet) are measured on these plots, respectively. Species, dbh and condition (merchantability) have been recorded before and after every treatment and at 5-year intervals between treatments since the study began. Individual trees ≥ 0.5 inch dbh have been numbered since the 1970s. Regeneration data also have been collected since the 1960s on three milacre plots located at the periphery of each 1/20-acre plot. Species and height class are recorded for seedlings 0.5 feet tall to 0.5 inch dbh.

The length of treatment and consistency of data collection in the PEF experiment are unusual, and allow a comprehensive long-term comparison of alternatives (see Kenefic et al. 2005b for additional examples). The 20-year selection and fixed diameter-limit cutting are particularly well-suited for comparison. There were no pretreatment differences in composition or structure between the stands, and a similar harvest interval facilitates analysis (Kenefic et al. 2005c). The focus of this report is on those two treatments.

Pretreatment Forest History

Researchers took photographs of the study area before the experiment was initiated. The photos show an irregular forest structure with significant components of mature softwood-dominated mixed-species stands in the understory reinitiation phase of stand development (Fig. 5). Although there had been no harvesting during the 50 years prior to the establishment of the Forest Service experiment, stand reconstruction data suggest that the forest had been partially cut repeatedly before the 20th century. There is some evidence of fire on the forest after early harvests of white pine, but the study area does not appear to have been cleared or burned extensively (Safford et al. 1969). Trees more than 150 years old at breast height are common in the study area (Kenefic and Seymour 1997; Seymour and Kenefic 1998), and some individual trees are more than 200 years old at breast height (unpublished data).

Treatments

Selection Cutting—The selection stands have been managed using a mathematically defined BDq structural goal with a target residual basal area (BA, trees ≥ 0.5 inches dbh) of 80 ft^2/acre, maximum residual dbh of 16 inches, and q-factor of 1.4 on 1-inch dbh classes (1.96 on 2-inch classes). Allowable cut is determined as the difference between pretreatment BA and posttreatment goal, and is distributed based on the target diameter distribution and marking and species composition guidelines. The marking guidelines are intended to improve residual stand quality, growth, and composition. In order of priority, we remove cull trees (stems > 50 percent unmerchantable by volume), high-risk and low-vigor trees, undesirable species, and trees at financial maturity (target maximum value). Crop trees are released and regeneration openings are created or enlarged. The regeneration method is a combination of single-tree and small-group selection.

Species preferences further guide removals, with BA goals of 35 to 55 percent for spruce, 15 to 25 percent each for balsam fir and hemlock, and 5 to 10 percent each for eastern white pine, paper birch, cedar and other. Because the percentage of spruce generally is less than this goal and the percentages of fir and hemlock are higher than the goals, we have discriminated against fir and hemlock and attempted to retain and release spruce. (Stand structural and compositional goals currently are in revision.)

Diameter-Limit Cutting—The fixed diameter-limit treatment uses thresholds for species removal as follows: 11 inches dbh for white pine, 9 inches for spruce and hemlock, 8 inches for paper birch and cedar, and all merchantable fir and other species. Over the study period these thresholds have varied by ± 1.0 inch, and the lower level of merchantability dropped from 6.5 to 4.5 inches dbh. All trees above the diameter limits except cull are removed and all trees below the diameter limits are retained. The study plan specifies that the stands are to be reentered when merchantable volume above the diameter limits equals that previously removed. For the three harvests conducted to date, this has resulted in a 20-year harvest interval coincident with the 20-year selection (note that the third cut in one of the diameter-limit replicates was delayed by five years due to slower volume regrowth).

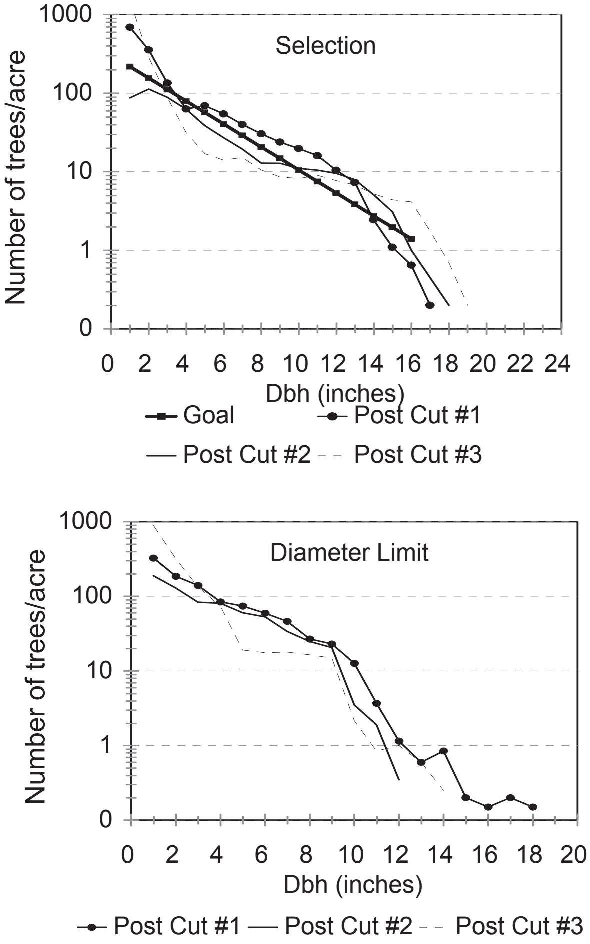

Figure 6.—Diameter distributions of the selection and diameter-limit cut treatments after each of the three harvests on the PEF.

Treatment Comparison

Kenefic et al. (2005c) reported the results of a comprehensive analysis of the 20-year selection and fixed diameter-limit treatments. Highlights of those findings are presented here.

Comparison of pretreatment stand conditions revealed no differences (significance level = 0.10) in volume (ft^3/acre) (p = 0.82), number of trees by size class (p = 0.76 to 0.86), or species composition (p = 0.14 to 0.61) between the two treatments. Three harvests were subsequently applied in the 1950s, 1970s, and 1990s (Fig. 6). A comparison of stand structure after the most recent harvest revealed significant differences between

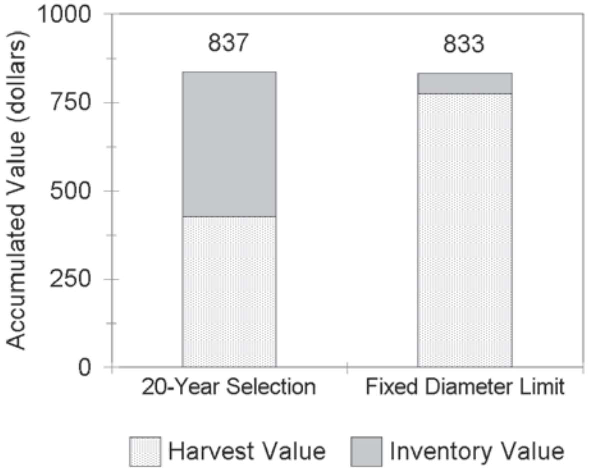

Figure 7.—Accumulated value per acre (harvest plus residual) in the selection and diameter-limit cut treatments after three harvests on the PEF.

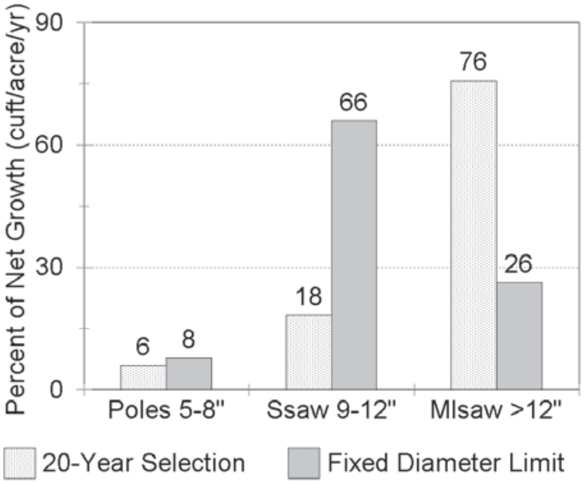

Figure 8.—Distribution of net growth among tree size classes in the selection and diameter-limit cut treatments on the PEF.

treatments; there were fewer trees in the small and medium–large sawtimber classes of the diameter-limit stands (p = 0.04 and 0.01, respectively). Harvest volume in the two treatments for the three harvests combined suggested that more volume was removed in diameter-limit cut stands (3,527 ft^3/acre) than the selection stands (2,518 ft^3/acre), though the difference was not statistically significant (p = 0.14). However, net actual harvest value discounted to year 0 at 4 percent was higher in the diameter-limit treatment ($774/acre versus $428/acre in the selection treatment) (p = 0.04).

At first assessment, the value of the harvests make the diameter-limit treatment appealing. However, the focus of silviculture is residual stand condition, so what was removed is less important than what was left. The value of the standing inventory after the third harvest was nearly 8 times greater in the selection than fixed diameter-limit treatments ($59/acre versus $409/acre) (p = 0.10). Interestingly, when we combined harvest value with residual inventory value to obtain the accumulated value, there was no difference between treatments (p = 0.98) (Fig. 7). This accumulated value index suggests no financial benefit associated with diameter-limit cutting over the approximately 45-year measurement period. However, data from the residual stands raise concerns about the impacts of the diameter-limit treatment.

Although neither total (gross) growth nor mortality were differentiated by treatment (p = 0.31 and 0.77), ingrowth was significantly greater in the diameter-limit stands (10.6 ft^3/acre/year versus 6.9 ft^3/acre/year in the selection stands) (p = 0.03). Diameter-limit cutting removed the largest trees with the largest crowns, and reduced growing stock to a lower level than the selection treatment. The lower strata of the diameter-limit stands were released and the amount of ingrowth (trees growing from sapling to merchantable size) increased. Thus, growth was concentrated on smaller trees (Fig. 8); in the selection stands, the proportion of net growth was greatest on trees > 12 inches dbh, i.e., the most valuable trees in the stand.

The long-term impact of cutting only large trees and concentrating growth on small trees is apparent when value per harvested tree is analyzed. Revenue generated per tree in the first cut was similar between treatments, with an average value of $2.07 per tree in the selection treatment versus $2.99 in the diameter-limit treatment (determined as gross harvest revenue; calculated in 1982 dollars using nominal prices adjusted by the all commodity Producer Price Index, divided by number of trees cut). However, in the third cut, the value of individual harvested trees in the diameter-limit treatment ($1.73) was less than half that in the selection treatment ($4.04). This suggests a trend of diminishing individual-tree value that accounts for lower total stand value, and further suggests reduced efficiency of harvesting operations because more trees must be cut to generate the same amount of revenue. The impact on harvest revenue likely is even more pronounced in hardwood stands where improvements in tree grade associated with large and good-quality trees add exponentially to value. Grade is not a consideration for the dominant softwood species (hemlock, fir, and spruce) on the PEF, so the effect of reduced maximum diameter and tree quality on revenues was mitigated somewhat by an increased harvest volume in the smaller classes.

Species composition also was affected differently by the two treatments. Spruce and fir are common associates in the northern conifer forest. They often occur together but management recommendations usually favor spruce due to its potential greater value, longer life span, and larger size. Shorter lived and prone to decay on poor sites, fir also is the preferred host of spruce budworm (*Choristoneura fumiferana* Clemens), which causes growth suppression and mortality during periodic outbreaks. One metric of compositional improvement is the ratio of spruce to fir. Ratios > 1 indicate more spruce than fir while those < 1 occur when fir is the dominant species. Prior to treatment, the spruce: fir ratio was 0.9 in the selection stands and 1.4 in the diameter-limit stands. After three cuts, the ratio was improved to 2.1 in the selection treatment, but had deteriorated to 0.5 in the diameter-limit stands.

Questions have been raised about the influence of the diameter limits on the PEF results. If high diameter limits were used, would stand degradation still have occurred? The answer lies in our understanding of how trees grow and stands develop. Within any age class, the better growing trees are larger, so diameter-limit cutting continually downgrades the growing stock. In stratified stands, trees restricted to upper strata may be eliminated. Raising the diameter-limit might postpone these effects but would not prevent their occurrence. This finding is supported by Sokol et al. (2004), who discovered that residual spruce in the PEF diameter-limit cut stands were consistently smaller than trees of the same age in the selection stands, and that the diameter-limit residuals had been slower growing throughout their lives. This supports the conclusion that diameter-limit cutting removed the faster growing trees.

Unmerchantable timber amounted to > 25 percent of stand volume after three cuts in the diameter-limit treatment, but < 1 percent of total volume in the selection treatment ($p = 0.03$). Lower stocking, smaller mean diameter, and a greater proportion of unmerchantable timber account for lower residual value. Hawley et al. (2005) established that only two cuts resulted in significant differences in genetic diversity of hemlock (a dominant species) in the PEF selection and diameter-limit stands. They found a higher number of rare alleles, which they believed were related to undesirable traits, e.g., poor form, vigor, or growth, in the diameter-limit stands.

It is important to note that our results represent the cumulative effects of repeated diameter-limit and selection cuttings. In fact, treatment disparity has increased over time. A preliminary analysis of the effect of partial cutting alternatives on residual volume, percent cull, percent spruce, and sawtimber density revealed that there were no significant differences between treatments after the first cut (Kenefic et al. 2004). However, the magnitude of treatment differences increased over time, resulting in less sawtimber and more cull in the diameter-limit than selection cut after two treatments, as well as less total volume and less spruce after the third treatment. These findings underscore the fact that the effects of diameter-limit cutting may not be immediately apparent but that repeated applications and a long-term perspective highlight issues of concern.

Conclusion

The concurrent presentation of results from the PEF in Maine and from Nyland's research in northern hardwoods in New York (this proceedings) support the conclusion that diameter-limit cutting degrades stand condition over time, relative to initial stand condition and alternative silvicultural treatment. It is compelling that the results of the two studies are so similar (see Nyland 2005 and Kenefic et al. 2005c, and Kenefic and Nyland 2005). The fact that comparable treatments in two different forest types resulted in similar outcomes suggests that our findings are relevant to diameter-limit cutting with retention of culls in general, and not the specific treatment applied or study area investigated.

The publication of the results from the PEF represents the first quantification of the long-term effects of repeated diameter-limit cutting, and the benefits of silvicultural treatment. It is our hope that this research will help landowners and practitioners better understand the implications of different forms of partial cutting.

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