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Cover Photo

Diameter-limit cutting in a northern conifer stand.

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Proceedings of the Conference on Diameter-Limit Cutting in Northeastern Forests

May 23-24, 2005
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Facilitating a Dialogue About Diameter-Limit Cutting

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Why a Conference About Diameter-limit Cutting?

Before embarking on an exploration of the specifics of diameter-limit cutting, we would be well served to ask ourselves, "Why is this topic important?" The answer to that question requires us to consider silviculture. Silviculture is "the art and science of controlling the establishment, growth, composition, health and quality of forests and woodlands to meet diverse needs and values on a sustainable basis" (Helms 1998). This definition highlights two critical features of silvicultural treatments: focus on residual stand condition and a long-term perspective.

Diameter-limit cutting means removing all merchantable trees larger than a specified diameter at breast height (Helms 1998). In practice, this usually involves the use of a fixed, or inflexible, diameter threshold, above which merchantable trees are harvested with retention of unmerchantable timber and without tending in the smaller size classes. Unlike silviculture, the focus of diameter-limit cutting is on what is removed, i.e. the largest and most valuable timber. A related practice is high grading, or removing the most commercially valuable trees from a stand. High grading is a more general term and encompasses diameter-limit cutting as commonly applied. Both practices are commodity driven: trees are selected for harvest based on an overriding interest in short-term revenue while bypassing the desirable features (focus on the residual and the long-term) of silviculture.

If the benefits of silviculture are acknowledged, why are commodity-driven harvests so common? An historical perspective provides some clues. Forestry, as a profession, became established in the Northeast in the late 1870s when the USDA Division of Forestry was formed, followed by state forestry commissions and forest societies in the 1880s and 1890s (Fernow 1913). Early reports of forestry practice, such as those by Austin Cary (1894) recounted the harvest of only the largest and best trees. In fact, diameter-limit cutting was recommended at the time as a means of preserving growing stock (Cary 1907, Murphy 1917). With no markets for anything but high-value trees, large trees were selectively removed under the guise of selection silviculture. See Pinchot (1905) or Westveld (1949) for examples.

Some foresters raised concerns about diameter-limit cutting as early as the 1900s. Murphy (1917) reported that diameter-limit cutting was common in the spruce regions, but warned that failure to improve the smaller size classes or retain thrifty trees of large sizes would prevent sufficient yield to make cuts periodically. Later research led Blum and Filip (1963) and Roach (1974) to question the sustainability of structure and growth in diameter-limit cut stands. Seymour et al. (1986) expressed concern about "short-sighted, financially motivated cutting," and encouraged wider application of silviculture. More recently, Kenefic et al. (2005) and Nyland (2005) concluded that repeated diameter-limit cutting reduced stand quality, value and long-term yields. Alternative silvicultural treatments were suggested (Kenefic and Nyland 2005).

Diameter-limit cutting is an integral part of our forest history in the Northeast, resulting in millions of acres of cutover lands. Many second-growth stands now contain poor quality stems, less valuable species, and variable stocking and crown cover as a result of past harvesting practices (Nyland 1992). At the dawn of the 21st century, Irland (1999) concluded that cutting in the Northeast generally was depleting stand quality and value far more than improving it.

Partial cuts focusing on extracting value continue to be widespread (Seymour 2005). Long-standing use of diameter-limit cutting has been little mitigated by findings from research about the benefits of silviculture. The short-term financial benefits of cutting only the largest trees are compelling. This raises a number of questions: What historical factors shaped the widespread application of these cutting practices and discouraged silvicultural treatments? What are the long-term impacts of diameter-limit removals on the region's forests? What are the economic and genetic implications? What are the ethical obligations of foresters considering diameter-limit cutting? And, perhaps most important, can we effectively rehabilitate the cutover forests of our region?

The papers presented in this report reflect the content of a two-day conference for forestry practitioners, researchers, policy makers, and landowners at the University of Massachusetts on May 23-24, 2005. We hope that this presentation of the conference papers will help to sustain a dialogue about diameter-limit cutting in the Northeast and increase interest in opting for silviculture instead.

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Historical Perspective on Diameter-Limit Cutting in Northeastern Forests

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Abstract

The use of diameter-limit cutting and high-grading is currently a concern for long-term sustainability of forests in the Northeastern United States and surrounding areas. This paper reviews historical information about the kinds of harvesting used in this region from 1620 to 1950, to provide a context for current discussions. Throughout this period, most timber harvests removed all trees that were in demand and that could be transported. Thus, nearly all harvests consisted of some type of diameter-limit cut, but the minimum diameter and the desired species varied so much that the harvests ranged from light partial cuts to nearly complete clearcuts. A period of widespread clearcutting from 1850 to 1920 to support the industrialization of the region created opposition to this practice, which resulted in attempts to shift most harvesting to some form of partial cutting. Thus, selection cutting (which often in practice was simply diameter-limit cutting or high-grading) became the method promoted by forest managers and silvicultural researchers for most forests in the early twentieth century.

Introduction

Throughout much of history, societies have obtained most wood products by cutting trees from accessible forests without providing for sustainable production of new trees (Perlin 1991). This kind of exploitative harvesting nearly always consists of a diameter-limit cut in which trees larger than a given diameter (based on the products needed) are harvested (Helms 1998). If large beams, posts, and boards are required, the diameter limit is generally set at 10 to 16 inches, producing a harvest entirely of sawlog-size trees. The limit is not necessarily uniform, but can vary among species and stem forms. If only desirable species of good stem quality above the minimum diameter are cut, this kind of selective cutting is often referred to as high-grading. In other situations where fuelwood, pulpwood, or similar products are in demand, the minimum diameter is set very low. These may amount to a clearcut harvest, although undesirable species are sometimes left standing. This kind of harvest is often called commercial clearcutting to distinguish it from the clearcutting regeneration method in which other site preparation or regeneration treatments would be incorporated.

This paper presents an overview of the methods of timber harvesting in the forests of the Northeastern United States from 1620 to 1950. The objective is to provide a historical context for current discussions about appropriate cutting methods for the region, particularly regarding the use of diameter-limit cutting. The paper focuses on the region encompassing the five New England states, plus New York, New Jersey, and Pennsylvania, but the general trends apply to surrounding areas as well. Figure 1 summarizes the types of harvesting generally used for the main species throughout this period. The range of harvests has been simplified to diameter-limit cutting for sawlogs vs. clearcutting in Figure 1. The diagram can give only a general outline of harvesting trends; details are provided in the text.

Agricultural and Early Industrial Eras (1620-1850)

Harvesting trees in the Northeast began as soon as settlements were established by English colonists in the 1620s. Native American peoples living in the region had modified the forest landscape through burning and clearing for agriculture, but they lacked the technology for widespread harvesting of trees (Cronon 1983).

The earliest colonial timber harvests were to supply products for local use--for building houses and other structures and for fuelwood. However, the North American forests contained trees that were larger and far more abundant than in English forests, so an export market developed very quickly. Much has been written about the trade in large white pines (*Pinus strobus*) for masts for the British Navy, and this was certainly an important aspect of the early timber industry, but these were not the first timber products exported. The first

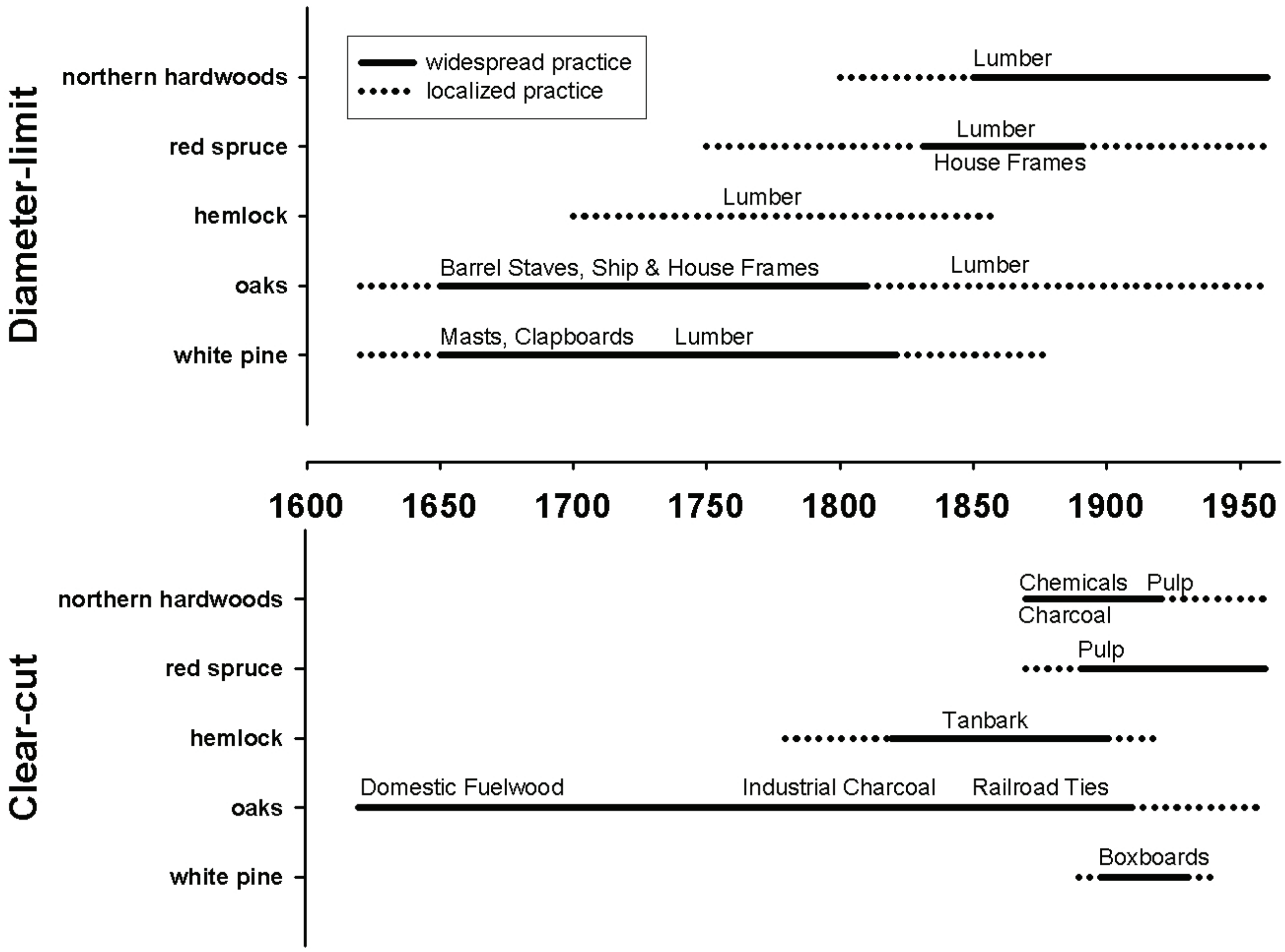

Figure 1.—Time line summarizing the types of exploitative harvesting generally used for the main tree species in the Northeastern United States from 1620-1950. Harvesting types are simplified into “diameter limit,” which refers to cuts that removed only sawlog-size trees, and “clearcut,” which refers to cuts that removed nearly all trees.

ships carrying goods from the North American colonies to England included a load of white pine clapboards (Whitney 1994) and oak barrel staves (Hawes 1923). This was in 1622-23, before sawmills were in operation, so the products had been made with hand tools.

By the 1630s, the first sawmills had been established along the coast of Maine, and their numbers expanded quickly in the following decades until most coastal rivers had multiple mills (Hobbs 1906; Perlin 1991). The main species harvested and the principal products were as follows: white oak (*Quercus alba*) for barrel staves for transporting liquid contents (mainly wine), and for beams and boards for shipbuilding and house construction; red oak (*Quercus rubra*) for barrel staves for transporting solid or gel contents (sugar and molasses), and beams and boards for house construction; white pine and red spruce (*Picea rubens*) for shingles, clapboards, boards, and for ship masts and yardarms; and Atlantic white-cedar (*Chamaecyparis thyoides*) for shingles (Perlin 1991; Gordon 1998; Irland 1999). The availability of large timbers in the American colonies for shipbuilding was so important that much shipbuilding shifted from England to New England (Perlin 1991; Gordon 1998). One interesting problem was that the stems of large white oak trees in New England were generally so straight that it was difficult to find the large stem-branch sections with curved grain to be used for the ships “knees” (Irland 1999), but this was not a major impediment.

The selection of pines for ship masts had particularly exacting requirements, because a mast was ideally made from a single tree. Masts needed to be made from conifers, because they required strength, yet had to be light and flexible. The British Navy had made use of Scots pine (*Pinus sylvestris*) from Norway and other northern European countries, but the large trees in those forests had already been cut, so masts had to be fabricated from pieces of smaller Scots pine (Manning 1979). The availability of single-tree masts from white pines in the North American colonies (some greater than 36 inches in diameter and 100 feet tall) was a great advantage over European sources. Mast logs had been shipped to England as early as the 1630s, but the trade began at a large scale in 1651. The famous Broad Arrow policy was put in place in a series of acts beginning in 1691, and it continued in effect until the Revolution in 1775. The Broad Arrow symbol was used by the British Navy to mark all of its property, and in this case, was used to designate all straight white pine trees 24 inches in diameter and larger (Manning 1979). Mast trees were the object of considerable controversy--the Navy's mast agents had to compete with the colonial timber cutters who would ignore the laws, and turn mast trees into clapboards, shingles, and boards at their sawmills (Perlin 1991).

The harvesting of mast trees was clearly a case of selective diameter-limit cutting (Whitney 1994). White pine occurred as a component in mixed stands containing hardwoods and hemlock (*Tsuga canadensis*). The mast harvesting focused on the emergent white pines that rose above the main overstory canopy. Initially, the harvesting of these selected pines was confined to the areas near the coast, but progressively moved up the coastal rivers.

Much more information exists about the kinds of products harvested in this era than about the original stand structure or the residual stand structure left following harvests. Although the special export products (barrel staves and ship masts) have received much attention, the wide range of wood products exported from Northeastern forests is revealed in accounts of two catastrophes: the destruction by fire of the cities of London, England in 1666 and Bridgeton, Barbados in 1668 (Perlin 1991). In both cases, most of the supply of beams, boards, clapboards, and shingles to rebuild these cities was provided by the New England colonies. They had clearly become a major source of general oak and pine construction materials. These products would have nearly all been a result of selective diameter-limit cutting of trees of sawtimber size of the desired species.

However, not all harvesting was of that type. Fuelwood was needed in great quantities in towns and cities; stands in the surrounding areas were heavily cut for this purpose after large trees had been removed for other products. These stands regenerated by sprouting, especially if chestnut (*Castanea dentata*) was prevalent, and as they were harvested again, even-aged coppice stands developed. Overland transportation of wood was so expensive that the area for fuelwood production was limited to 5-20 mile radii around settlements (Whitney 1994). Local stands were unable to supply the fuelwood needs of Boston and other cities within decades of settlement, and fuelwood was generally scarce in heavily populated areas of the east coast by 1800 (Whitney 1994). Much fuelwood was transported by ship to these areas from remote forests.

The forest structure left by timber and fuelwood cutting would have varied geographically with accessibility and distance to towns. At the most distant points from population centers were forests that had been lightly high-graded for mast pines. In more accessible areas, a heavier diameter-limit cutting of oaks, pines, and other species would have occurred for boards, beams, shingles, and barrel staves. The areas closest to settlements consisted of agricultural land and woodlots that would have ranged from high-graded stands to nearly even-aged coppice stands. These zones progressively spread outward over time, as population and agricultural areas expanded; however, remote areas of the Northeast still had much of their virgin timber intact in 1850, 200 years after initial European settlement, largely because of the difficulties of overland transportation.

Silvicultural Ideas, Practices, and Policies

Few laws or regulations controlled timber harvesting in this era, except for those that specified ownership of land or trees. The Broad Arrow policies were designed to reserve mast trees for the Navy, not to plan for sustained production of those kinds of trees. There were some laws that protected smaller trees from cutting, to provide growing stock for future harvests; one example is an order for the town of Woburn, Massachusetts in 1640 that protected oaks less than 8 inches in diameter from cutting, thus mandating diameter-limit cutting to maintain trees for the future (Hawes 1923). However, there is little evidence that such laws were widespread. The main practice in use in settled areas at this time was a rough kind of coppice harvest with a rotation of about 25 years (Whitney 1994).

Era of Clearcutting for Wood-Based Industries (1850-1910)

The Industrial Revolution during the mid-nineteenth century broadened the kinds of wood being used from the forests in the Northeast and increased the volumes needed to sustain the growing industries, cities, and populations within the region. In particular, the development of industries such as pulp and paper, industrial charcoal, and boxboards, which utilized large volumes of lower quality wood, shifted the focus of timber harvesting activities in much of the Northeast from the selective cutting of large, high quality trees to heavy cuttings in which nearly every tree was considered merchantable.

The timing of the increase in industrial uses of wood varied across the region. It began earliest near the population centers along the Atlantic coast and the major rivers, where there had already been more than one wave of diameter-limit cutting, as well as coppice cutting for fuelwood in some cases. The shift in cutting practices from diameter-limit cutting of sawlogs to clearcutting occurred much later in the northern and western portions of the Northeast. Much of this area, including the Adirondacks, northern Maine, and central and western Pennsylvania had been largely inaccessible prior to the 1850s (Whitney 1994). With the advent of the railroad in the 1830s (Muir 2000), the logging industry was able to expand into these remote areas, resulting in a new wave of diameter-limit cutting for sawlogs, but this shifted to clearcutting quickly. The process of this shift is described separately for the four main forest types, which were controlled by different markets.

Oak-Pine Forest Type

Extensive agricultural abandonment in the 1850s resulted in the development of large expanses of white pine forests on former agricultural fields, mainly in southern New England (Foster and O'Keefe 2000). In areas that had remained forested during agricultural expansion, repeated diameter-limit harvesting for sawlogs and extensive cutting for fuelwood created stands containing predominantly coppice hardwoods or low value hemlocks. While the amount of forested area greatly expanded in the region during this time period, the size and quality of the trees were much lower than what had supplied earlier forest industries.

An industry formed around these second-growth stands, which ranged from 50 to 100% white pine, and were even-aged, but of poor quality (Westveld 1935; Gould 1960). The trees had many large branches, and were deformed by the white pine weevil (*Pissodes strobi*), but they were still perfectly acceptable for boxboards—the short boards used for many types of shipping containers (crates and boxes). These were generally harvested with nearly complete clearcuts that left only advance regeneration hardwoods. This industry grew to its largest extent from 1890 to 1920.

Cordwood of various hardwood species was the only source of home heating until coal and coal stoves became readily available in the early 1800s. Coal stoves became numerous enough to have a substantial effect on fuelwood demand in cities by 1830, and there was a steady shift from wood to coal as a percent of the energy source used in the region (Whitney 1994). However, even as this shift occurred, the increased heating demand for all energy sources from the growing population meant that wood use for domestic heating reached a peak in 1870. Despite this peak in the late 1800s, there was still significant cordwood cut for use in rural areas as late as the 1920s.

Industrial charcoal added to the demand for fuelwood to be used for iron, brass, lime, and brick production. Although it was not nearly as important as domestic heating in total use of cordwood supplies, it had significant effects on regions where these industries were located, including southern New England, northern New

Jersey, and western Pennsylvania. Iron furnaces had very large fuelsheds, and often these operations continued widespread clearcutting until the wood supply was exhausted, leaving large areas of young sprout hardwood regeneration.

Hardwood railroad ties also gained importance at this time. Each mile of new railroad and trolley track needed more than 2500 ties, mostly made of oak (Gordon 1998). These could be obtained from small trees as part of heavy fuelwood cutting.

Hemlock Forest Types

Hemlock was a component species of many forest types throughout the Northeast, and was the most abundant species in many cases. It was less desirable than pine or spruce as a timber species, but the larger hemlocks were sometimes cut with the other conifers in diameter-limit harvests. A major shift in the demand for hemlock came when it was discovered that its bark was an excellent source of tannins for treating leather. The earliest tanneries in the United States were small operations in southern New England that had only local importance (Bürgi et al. 2000). They initially used oak bark as the source of tannins, following the European methods that relied on oak and spruce. However, hemlock became the main source in the Northeast by 1800 (Millen 1995).

Large tannery operations were established in the Catskills in the 1820s because of the predominance of hemlock in the area. Hemlocks were felled and the bark was peeled and hauled on sleds to tannery sites, with the hemlock logs generally left in the woods. By 1850, the hemlock supply was declining in the region, with much of the land having been clearcut. The industry moved to the Adirondacks, Maine, and Pennsylvania where hemlock was still abundant. A major center for tanneries was in north-central Pennsylvania (Irland 1999). Logging in that region had begun in 1850 to selectively remove the large pines. As the pine was depleted, hemlock was cut for lumber production; then the harvesting for tanneries began, with both bark and logs being used. Large water-powered tanneries were established in the 1870s, and surrounding stands were cut so clean that settlers easily converted many of the post-harvest areas to farms. These were not restricted to areas with good river transportation; tanneries were also distributed along the railroads of the area. Tanbark was shipped out by rail to operations in other regions, as well as for use by local tanneries. The operations in this region declined as the hemlock supply was exhausted, and the leather finishing process changed to the use of chrome salts instead of tannins in the 1890s.

Spruce-Fir Forest Type

The history of diameter-limit harvesting of red spruce in northern New England and the Adirondacks was quite different from that of other species. In contrast to the moderately tolerant white pine and oak, which typically failed to regenerate high quality stems after diameter-limit harvesting, the shade tolerance and abundant advance regeneration characterizing red spruce allowed it to survive and develop in height following these harvests (Westveld 1939). Early diameter-limit harvesting of red spruce focused primarily on procuring sawlogs to fuel the thriving lumber industry throughout the Northeast (Whitney 1994; Welsh 1995; Gove 2003). While much of this industry had been built on white pine lumber, red spruce was quickly recognized as a valuable substitute for this much-depleted resource (Whitney 1994). Red spruce quickly replaced white pine as the major species being cut for lumber in the Adirondacks and Maine by 1850-90 (Cary 1896; Welsh 1995). Early sawlog harvests of red spruce focused solely on larger diameter trees above 12-16 inches (Linn 1918; Churchill 1929; Dana 1930; Seymour 1992; Welsh 1995). These large-diameter trees quickly became rare, but improving markets for spruce lumber (Gove 2003) resulted in repeated cutting of these stands to successively lower diameter limits (Seymour 1992). By the 1890s all trees above a stump diameter of 8-10 inches were being harvested (Churchill 1929; Seymour 1992; Welsh 1995).

A technological development then changed the demand and harvest methods for red spruce. The northern hardwood-red spruce type extends south into the Berkshire Plateau region of western Massachusetts. This overlap between the heavily industrialized part of southern New England and a supply of spruce led to the early use of wood for paper production. The first wood-based pulp mill in the United States was established in a converted textile mill in the town of Lee, MA in 1867 (Gordon 1998). The harvesting method consisted of removal of all red spruce and balsam fir (*Abies balsamea*). The number of pulp mills in this area expanded so rapidly that the spruce and fir supply was exhausted by 1890 and the mills began to close. The paper industry shifted east to mills in the city of Holyoke on the Connecticut River, and the pulpwood harvest moved to Vermont and New Hampshire, with the spruce and fir pulpwood being driven on the River to the mills (Whitney 1994; Muir 2000).

This increased emphasis on harvesting pulpwood resulted in continued lowering of the diameter-limit to levels as low as 5 inches in places such as the Adirondacks (Churchill 1929; Juvenal 1906 cited in Welsh 1995). In addition to these lower diameter limits, balsam fir, a species primarily ignored in earlier spruce harvests, was also cut for pulpwood (Oosting and Reed 1944). As the demand for pulp increased and new, previously inaccessible areas of forest were opened to logging via railroad expansion, harvesting practices changed to extensive clear-cutting for pulpwood throughout the region (Westveld 1928; Dana 1930; Oosting and Reed 1944; White and Cogbill 1992; Welsh 1995).

Northern Hardwood Forest Type

Diameter-limit cutting was less widespread in the northern hardwood forests of northern New England and the Adirondacks during the industrial era. Logging during this period was generally restricted to the most accessible hardwood stands because hardwood logs do not float; this changed with the advent of widespread railroad systems (Linn 1918; Dana 1930; Blum and Filip 1963). Harvesting within these stands was very selective and typically only removed the larger, well-formed hardwoods for use in furniture making and other construction purposes (McQuilkin 1957; Gilbert and Jensen 1958; Blum and Filip 1963). In addition to these diameter-limit harvests, accessible northern hardwood stands were also clearcut during this period for fuelwood, as well as to supply the charcoal and chemical distillation industries (Gilbert and Jensen 1958).

In areas of the Northeast where these northern hardwood stands contained a red spruce component, such as New Hampshire and Vermont, diameter-limit harvesting of red spruce was a widespread practice (Linn 1918; Dana 1930). Initial harvests in these stands during the late nineteenth century focused solely on selectively removing red spruce, with a minimum diameter limit of 12-14 inches (Linn 1918; Bormann et al. 1970; White and Cogbill 1992). However, in most cases these harvests served to increase the proportion of hardwood species in the stand at the expense of spruce (Linn 1918; McCarthy 1919). The use of logging railroads in these regions (Oosting and Reed 1944; White and Cogbill 1992) and the introduction of new markets for hardwood species and smaller diameter red spruce resulted in clearcutting of these stands in subsequent harvests. As a result, clearcutting was practiced extensively in these mixed species forest types (as in the spruce-fir type) at the turn of the nineteenth century and beginning of twentieth century (Oosting and Reed 1944; Bormann et al. 1970; White and Cogbill 1992; Schwarz et al. 2001).

Silvicultural Ideas, Practices, and Policies

The hardwood charcoal production for the iron industry in Pennsylvania and the white pine boxboard industry in southern New England led to some of the first attempts at industrial forest management in the United States to use managed coppice and shelterwood methods. However, the greatest response to the heavy industrial clearcutting was a call to reserve valuable trees on the sites rather than to simply cut all commercial stems. This was focused on red spruce, likely because of the speed with which this species was harvested.

Slash fires, extensive damage to residual trees, and the failure of red spruce to successfully regenerate following clearcutting resulted in several early calls of concern regarding clearcutting in the spruce-fir region at the turn of the nineteenth century (Cary 1894; Pinchot 1898; Ayres 1903; Merrill 1959). Early foresters such as Gifford Pinchot and Austin Cary advocated harvesting systems that cut red spruce only above a set diameter limit between 10-14 inches due to the previous success of diameter-limit cutting in regenerating red spruce (Cary 1894; Pinchot 1898). Large-scale clearcutting in the spruce-fir forests of Vermont led the governor to include in his address to the state in 1894 a recommendation for the implementation of a 10-inch diameter limit in spruce forests (Merrill 1959). Similarly, the New Hampshire legislature discussed proposals during the 1890s for laws restricting harvesting spruce below a given diameter limit (Ayres 1903). Thus, a major initial impetus for forest conservation in the 1890s was the shift from partial cutting of spruce stands to clearcutting, with the proposed solution being to reinstate diameter-limit cutting as the preferred harvest method.

Era of Early Silviculture and Forest Conservation (1910-1950)

Oak-Pine Forest Type

In the early twentieth century, most of the market demand that had led to clearcutting in the oak-pine type began to disappear. Domestic fuelwood, industrial charcoal, tanbark, and chemical wood were all being replaced by coal, oil, and petroleum-based chemicals. The pine boxboard market continued through the 1950s and beyond, but at a much reduced scale due to the effects of the 1938 hurricane and the development of cardboard packaging. Much of the landscape was covered with young even-aged stands, having few trees of merchantable size for sawlogs.

In contrast, the value of high-grade hardwoods and pine was increasing at that time for furniture, flooring, and finish material (Gordon 1998). A substantial demand also continued for lower grade hardwood for railroad and trolley ties. These market conditions would be expected to lead to cutting methods that either favored the production of larger timber through thinning, or focused on cutting only sawlog trees. However, clearcutting continued to be common. This was in part simply because it was a "deeply ingrained practice" in the region (Cline 1944). Also, most milling was done with portable sawmills, and once set up, the crews insisted on cutting every merchantable tree in the area (Hawes 1929). Forested land had such low value in southern New England, that timber sales sometimes included the land itself, and the sawmill crews generally clearcut the tract. If only the timber was included in a sale, it was generally specified that the cutting rights were for trees greater than a specified diameter, thus requiring a diameter-limit cut; these practices continued through the 1950s (D.M. Smith, personal communication, 2005).

However, there were economic arguments being developed in this period that called into question the financial benefits of clearcutting. The general rule at the time was to cut every tree that met the minimum merchantable criteria for the available market. Time and motion studies and sawmill yield analyses led to the conclusion that "often there is no profit, but instead a loss, in cutting small trees even though of size to give merchantable products" (Hawley 1938). Hawley noted that this was not news to professional foresters, but it had not been communicated widely. An example of research on this topic was that of Cunningham and Ferguson (1946) on harvesting hardwoods for railroad ties in Connecticut; the conclusion was that ties should be made from trees 18 inches and larger, rather than using trees as small as 10 inches, as was commonly done.

In addition, foresters and legislators were advocating selection cutting at that time (see further discussion below), even though much of the cutting that was described as selection was diameter-limit or high-grading. Thus, a combination of clearcutting, diameter-limit cutting, and high-grading continued in the pine-oak region throughout the period.

Spruce-Fir Forest Type

Despite early concern regarding the sustainability of clearcutting practices within the spruce-fir region at the turn of the nineteenth century, this continued to be the predominant mode of harvesting during the early and mid 1900s (Westveld 1928, 1939; Oosting and Reed 1944; White and Cogbill 1992; Welsh 1995). This was motivated primarily by the needs of a thriving pulp and paper industry in the Adirondacks and northern New England (Harper 1947; Oosting and Reed 1944; Welsh 1995). The development of harvesting technology such as logging trucks and tractors in the 1920s (Oosting and Reed 1944; Welsh 1995) and chainsaws and rubber-tired skidders in the 1940s and 1950s (Cogbill and White 1992; Welsh 1995) increased the efficiency with which remote areas within this region could be harvested to supply the large demand for pulpwood.

Within the spruce-fir forests of Maine, much of the red spruce diameter-limit harvests in the late 1800s had resulted in an increase in balsam fir in residual stands by the early 1900s (Zon 1914; Seymour 1992). As a result of the artificially high abundance of fir on the landscape, an extensive spruce budworm (*Choristoneura fumiferana*) outbreak occurred from 1913-1919, causing widespread mortality of merchantable spruce and fir throughout the region (Seymour 1992). To forestall pulpwood shortages, harvesting operations following these outbreaks in the 1920s covered extensive areas, salvaging damaged stands and clearcutting stands that had survived the outbreak (Seymour 1992).

The devastating impacts of the budworm on the long-term pulpwood supplies combined with continued criticisms of clearcutting resulted in a reevaluation of the silvicultural systems most appropriate for spruce-fir stands (Murphy 1917; Dana 1930; Westveld 1939; Harper 1947; Westveld 1953). In many cases, suggestions included the use of true selection systems to promote spruce and fir reproduction and maintain a greater amount of merchantable growing stock (Zon 1914; Murphy 1917; Harper 1947; Westveld 1953). However, these suggestions were often misapplied in the form of diameter-limit harvests (Murphy 1917) or criticized due to the propensity of residual stands to windthrow damage (McCarthy 1919; Dana 1930; Fletcher 1944). To avoid these losses to windthrow, diameter-limit cutting to a very small diameter was suggested as an alternative to selection systems, particularly in situations such as spruce flats where spruce and fir advance regeneration were abundant and risk of windthrow was high (Linn 1918; Westveld 1928; Dana 1930); this kind of cut would now be called an overstory removal (i.e., a clearcut that reserves advance regeneration). As a result of these suggestions, both overstory removal and diameter-limit harvests of sawtimber red spruce became the predominant modes of harvesting from the 1940s through the 1960s (Oosting and Reed 1944; Harper 1947; Hart 1963).

Northern Hardwood Forest Type

Improvements in logging technology and the development of new markets for hardwood veneer and pulp resulted in increased utilization of northern hardwood forests from the 1910s through the 1950s (Dana 1930; McQuilkin 1957; Blum and Filip 1963). Harvesting practices in these forest types over this period ranged from large-scale clearcutting for pulpwood and chemical wood to diameter-limit harvests of high quality veneer logs from previously inaccessible old-growth stands (Dana 1930; Gilbert and Jensen 1958; Blum and Filip 1963). In many cases, large diameter hardwoods were selectively removed from stands that had previously been harvested for red spruce during the late 1800s and early 1900s (Blum and Filip 1963; Bormann et al. 1970). By the 1950s, these harvesting practices had resulted in much of the hardwood forests in the region existing in a fairly degraded state. Despite earlier management guidelines advising the removal of cull or 'wolf' trees during diameter-limit harvests (Dana 1930), most stands subject to repeated diameter-limit harvests were now predominantly composed of large, poor quality stems interspersed with smaller, non-merchantable trees (Westveld 1956; Gilbert and Jensen 1958; Blum and Filip 1963).

Despite the degraded state of many northern hardwood stands, the strong markets for large veneer-quality hardwood logs necessitated the development of silvicultural guidelines for sustainably managing these stands (e.g., Gilbert and Jensen 1958; Blum and Filip 1963). In general, selection systems became the preferred approach for northern hardwood stands (Blum and Filip 1963). While these management recommendations included the removal of cull hardwoods, the misapplication of these selection systems resulted in the continued degradation of many old-growth stands in the region (MacAdam 1950).

Silvicultural Ideas, Practices, and Policies

The early calls for using diameter-limit cutting for red spruce in the 1890s (as an alternative to clearcutting) were continued in the early twentieth century, and expanded to other forest types. Gifford Pinchot advocated selection harvesting, which was acceptable to the logging industry because it was economically feasible (Boyce and Oliver 1999). The harvesting was often actually diameter-limit cutting or high-grading, but it was a clear improvement over widespread clearcutting. Forestry journals and textbooks (e.g., Hawley 1946; Meyer 1952) began to add the ideas and experience from Swiss and German selection forestry to the simple approach of partial cutting. A good deal of U.S. Forest Service research was focused on growth-and-yield and regeneration in partially cut stands, and selection cutting was promoted in advice given to private landowners (e.g., Hawley and Goodspeed 1932). Foresters devised many variants of the method; the terms "economic selection", "improvement selection", "maturity selection", "war-timber selection", and "businessman's selection" (as well as "single-tree" and "group" selection) were all discussed in the Journal of Forestry in the 1930s-50s. Some of these were creative applications of selection principles to specific forest types to promote regeneration and long-term economic goals; others were devised to meet short-term financial goals.

In the Northeast, any kind of partial cutting was seen as an improvement over the clearcutting that had been prevalent. For example, Cline (1944) noted that: "This very practice of clearcutting has been the largest single factor contributing to the decline of Massachusetts forests during the past 50 years." Some of the opposition to clearcutting resulted from associating the drastic overcutting that was occurring at a landscape scale with the clearcut harvest method being used. The possibility of federal regulation of cutting on private lands was being considered, and New England states were debating and in some cases passing state regulations as an alternative (Lambert 1944; Merrill 1959). Some of these sought to reduce clearcutting, but with minor requirements such as retaining seed trees.

An example of the lack of discrimination concerning the kind of partial cutting to be promoted is found in a brochure of The New Hampshire Forestry and Recreation Commission (1947) that dealt with forestry problems in the state. Two photographs (Fig. 2) show the harvesting method to be avoided (a clearcut lot) in contrast to the appropriate method (a selectively cut lot). Close inspection of the photographs shows that the residual stand left after selective cutting is made up of tall, thin trees with small crowns, recently of suppressed or intermediate crown classes, scattered among large stumps. This appears to be a ill-conceived diameter-limit cut of an even-aged stand, yet is presented as a harvesting method to be emulated.

Hawley (1938) considered partial cutting as an easy way to introduce private landowners to forest management, similar to Pinchot's use for initially engaging forest industry in improving their practices. However, Hawley did not consider it the best alternative for all stands. He wrote: "…in the effort to take advantage of partial cutting and selective logging as a bait for leading private owners into the practice of forestry, professional foresters have in some instances attempted to extend this style of cutting to situations outside its legitimate range. It has in some cases amounted almost to a deification of partial as contrasted to complete cutting of the stand."

The period of 1920-50 had clearly become a time when selection harvesting had gained the support of most of the forestry profession, but in many ways the choices of harvest method (as actually practiced) had not advanced very far beyond clearcutting vs. diameter-limit cutting for sawlogs. The landscape-level problems with clearcutting were clear, and there was interest in re-vegetating watersheds, restoring and maintaining landscape aesthetics, and producing large high quality timber. But Hawley gave one of the strongest warnings about shifting without question to the other alternative, when he wrote: "Let us … envision the future results of any partial cutting … not only on the basis of the immediate financial profit of the operation, but also upon its ultimate consequences. Use the propaganda value of selective logging for all it is worth, but be honest with yourself and do not be led into thinking that partial cutting or selective logging is a panacea which will solve all the problems of silviculture."

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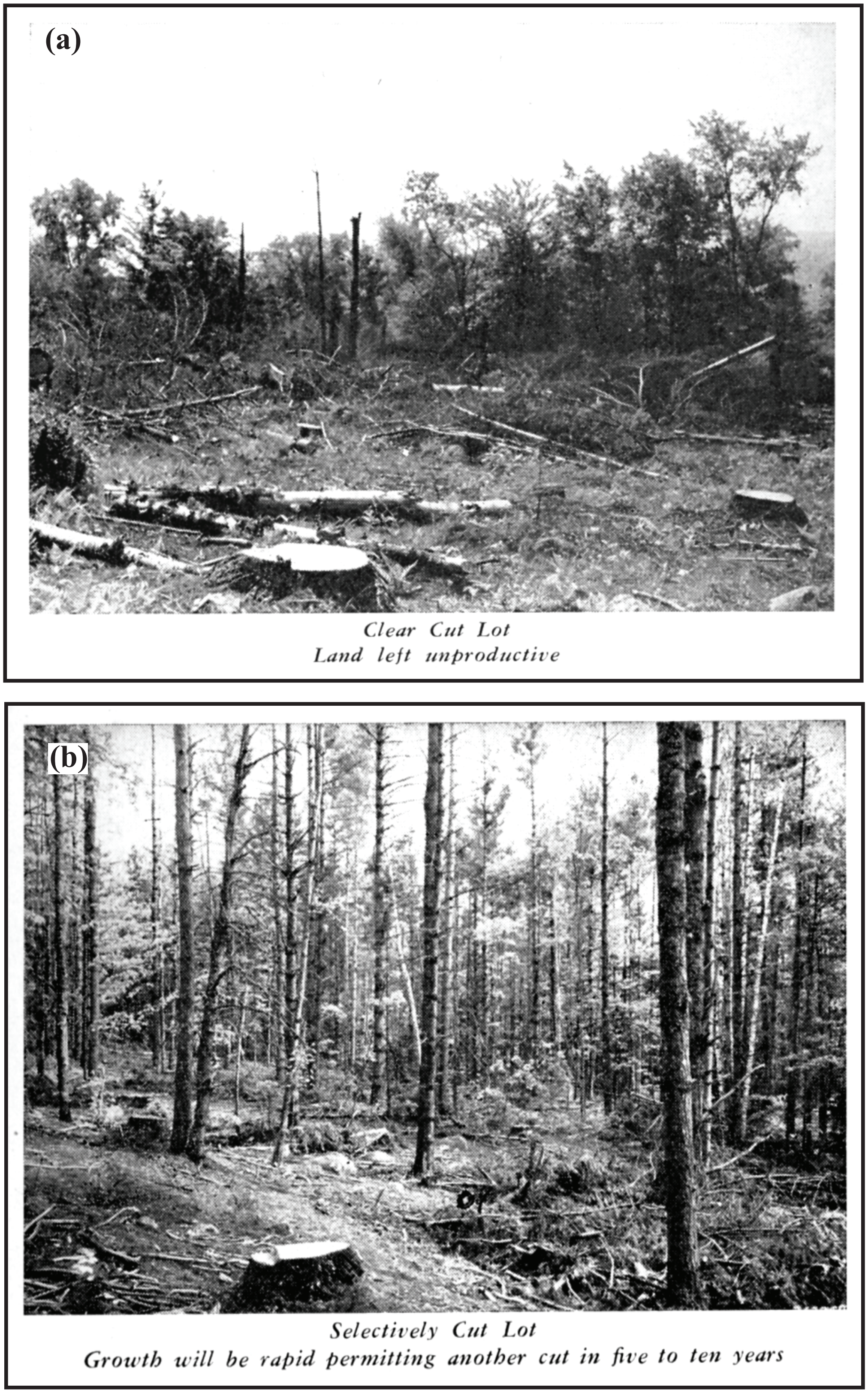

Figure 2.—Photographs originally presented by the New Hampshire Forestry and Recreation Commission (1947) indicating the ideas about preferred harvesting methods that were generally held in the first half of the 20th century. According to these ideas, clearcutting (A) was to be avoided in favor of selective cutting (B). However, many of the very heavy cuts tended to produce the best regeneration, whereas many selectively cut stands were left with poor-quality residual trees.

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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.

[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.

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.

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, 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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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.).

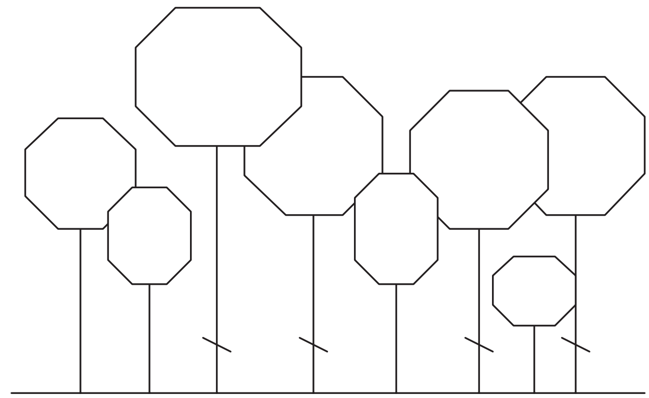

Figure 1.—Trees differentiate into crown classes in even-aged stands of single species. Hash markets indicate trees removed in diameter-limit cutting.

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

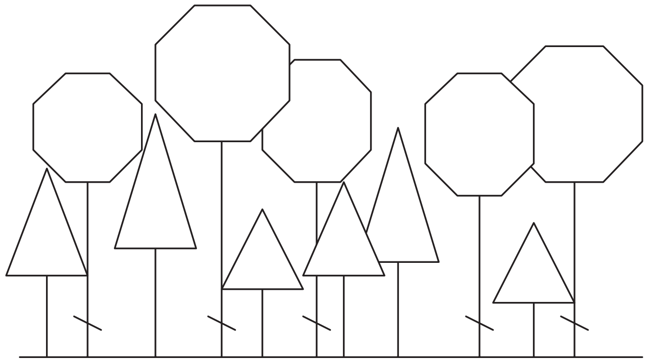

Figure 2.—Mixed-species, even-aged stands have a stratified structure, with crown classes occurring within individual layers. Hash markets indicate trees removed in diameter-limit cutting.

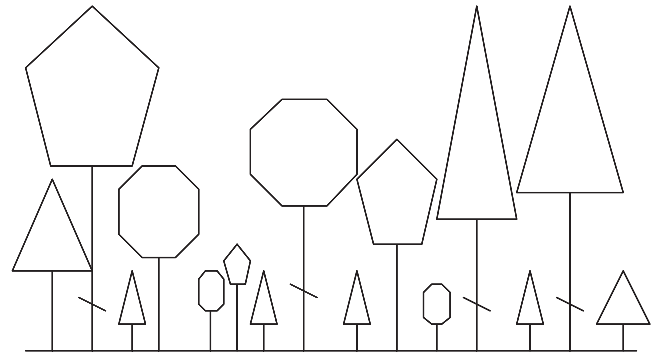

Figure 4.—Mixed-species, multi-aged stands have a complex structure. Different age classes and species form multiple strata, with differentiation into crown classes within each. Hash markets indicate trees removed in diameter-limit cutting.

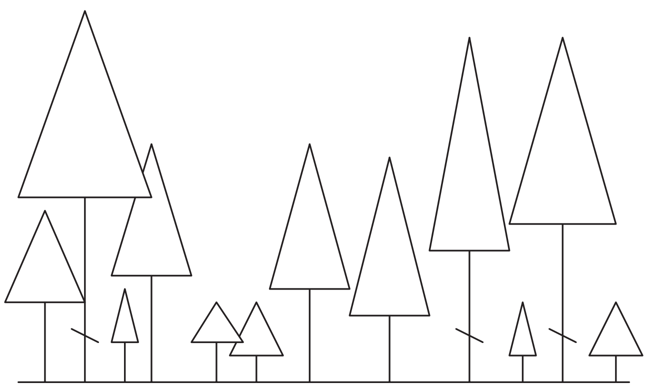

Figure 3.—Multi-aged stands of a single species have strata composed of different age classes, with differentiation occurring within each layer. Hash markets indicate trees removed in diameter-limit cutting.

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.

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).

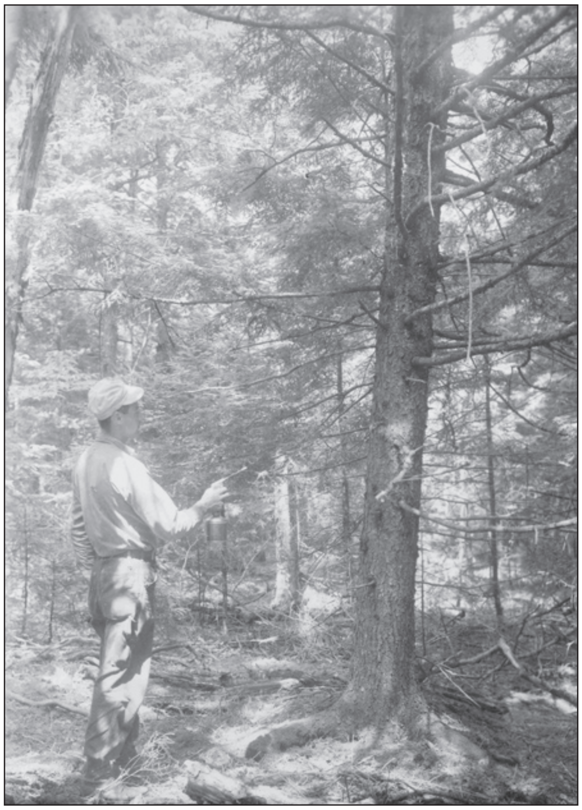

Figure 5.—Pretreatment photos from the 1950s suggest that the PEF was a mixed-species, conifer-dominated forest with irregular stand structures.

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

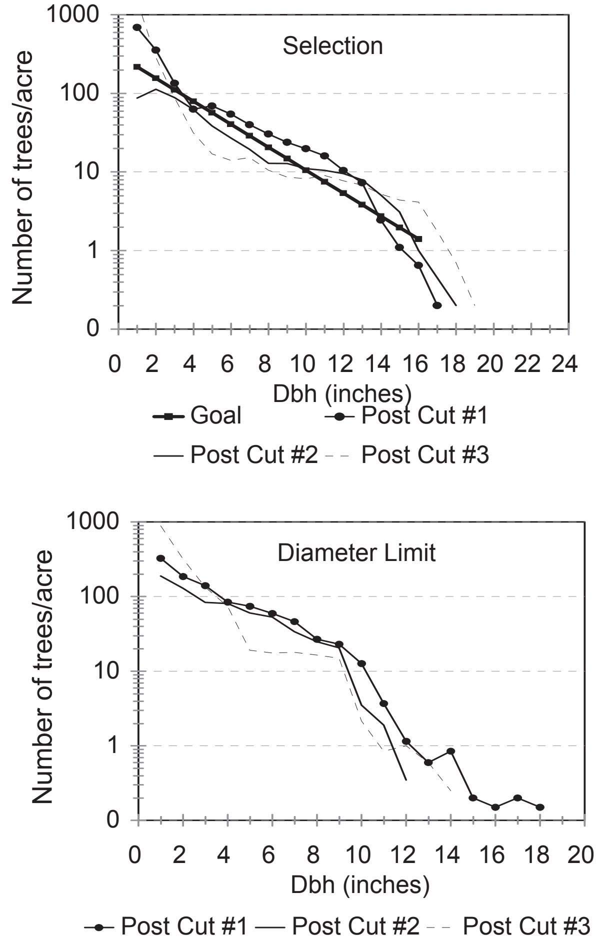

Figure 6.—Diameter distributions of the selection and diameter-limit cut treatments after each of the three harvests on the PEF.

(note that the third cut in one of the diameter-limit replicates was delayed by five years due to slower volume regrowth).

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

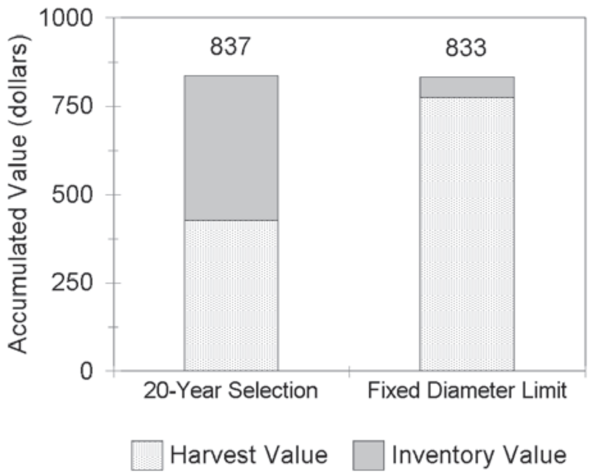

Figure 7.—Accumulated value per acre (harvest plus residual) in the selection and diameter-limit cut treatments after three harvests on the PEF.

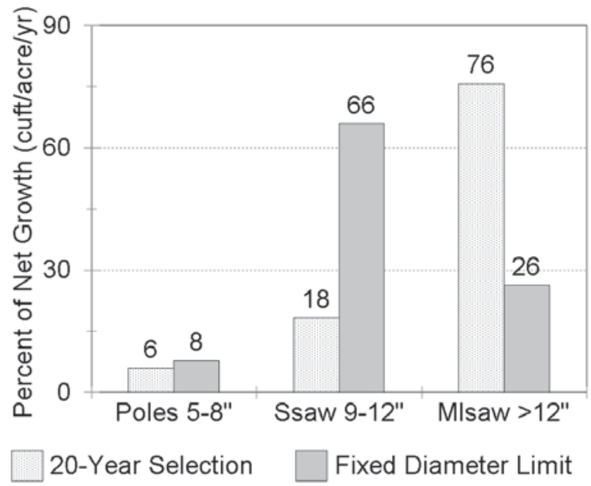

Figure 8.—Distribution of net growth among tree size classes in the selection and diameter-limit cut treatments on the PEF.

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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Research on Diameter-Limit Cutting in Central Appalachian Forests

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Introduction

In their abundance and quality the mature, second-growth forests of the Central Appalachian region are a valuable timber resource for landowners, forest industries and the general public. As these forests are harvested, maintaining their productive capacity and conserving tree species diversity are important considerations for long-term sustainability according to the Montreal Process Criterion and Indicators (http://www.mpci.org/criteria_e.html). Current stands typically contain more than 20 tree species representing a range of silvical characteristics (Miller and Kochenderfer 1998; Brashears et al. 2004). As a result, establishing new cohorts with species representative of the forest that preceded them requires planned silvicultural treatments before harvest. Long-term silvicultural research has produced guidelines for sustainable management of these forests (e.g., Roach and Gingrich 1968; Smith and Eye 1986; Nyland 1987; Marquis et al. 1992) that are used widely on publicly owned lands in the region (USDA For. Serv. 1986).[1] However, these guidelines are rarely followed on most of the private land in this region or elsewhere in the Northeast (Fajvan et al. 1998; Pell 1998; unpublished data).

Because private nonindustrial forests account for nearly 80 percent of forest ownership in the Central Appalachians (Smith 1994), harvesting practices on these ownerships affect landscape attributes such as wildlife habitat, scenic quality, recreational opportunity, and economic value. Forest industry is the foundation to sustaining these values by making forest management economically feasible for landowners. Yet in 1995, assessments of timber harvesting practices conducted in three states suggested that these practices threaten the diverse supply of raw materials essential to support such an industry (Fajvan et al. 1998; Pell 1998; unpublished data). Forest sustainability also can be affected because the most vigorous overstory trees are removed during a diameter-limit harvest. Although trees in the intermediate crown class and understory trees receive more growing space, many of these low-vigor stems will die or grow slowly (Marquis and Ernst 1991). There also is a reduction in seed sources of high-value species that are selectively removed (high-graded) down to the smallest merchantable diameters. For example, in West Virginia, 36 percent of the harvests surveyed in 1995 showed reductions of more than 80 percent in basal areas of northern red (*Quercus rubra*) and white oaks (*Quercus alba*), yellow-poplar (*Liriodendron tulipifera*), ash (*Fraxinus Americana/Fraxinus pennsylvanica*), and black cherry (*Prunus serotina*) (Fajvan et al. 1998). Such reductions have important implications for future timber supply, stand productivity, and economic returns available to landowners. Biodiversity and ecosystem resiliency also are affected as species are selectively removed during repeated partial harvesting (Schuler 2004).

Diameter-limit harvests (or any partial canopy removal harvest) are classified as minor disturbances (Oliver and Larson 1996) because some trees that predate the disturbance survive. These trees may increase in growth if they are healthy, have sufficient live crowns and are undamaged from logging. Alternatively, if the residual trees previously were in subordinate crown positions, their growth increase may be marginal, stem quality may be lost due to epicormic sprouting, or mortality can occur (Roach and Gingrich 1968). If sufficient growing space has been created by the harvest, regeneration may develop from new seedlings, advance regeneration, and sprouting.

In this paper I review past and current research on the effects of diameter-limit harvesting on the stand structure, productivity, regeneration, and overall sustainability of even-aged hardwood forests. Results of past monitoring studies in West Virginia, Pennsylvania, and New York are summarized, and new data are presented from long-term studies on the West Virginia University Forest.

[1]An evaluation of the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry under the SCS ConservationProgram (2005). Unpublished report available from the Pennsylvania Bureau of Forestry, Harrisburg.

Review of Research on Diameter-Limit Harvesting

1995 Timber Harvest Assessment

In 1995, scientists and managers in New York, Pennsylvania, and West Virginia examined postharvest stand attributes in an attempt to describe future forest sustainability. Ninety-nine harvests were sampled in West Virginia, and 99 and 62 harvests were sampled in Pennsylvania and New York, respectively. Following examination of pre- and postharvest stand structures, analyses focused on describing harvesting practices and resulting effects on sustainability. The studies confirmed that diameter-limit harvesting was practiced on about half of the harvests surveyed in New York (unpublished data) and Pennsylvania (Pell 1998), and on 80 percent of the harvests in West Virginia (Fajvan et al. 1998). The remaining harvests consisted of intermediate treatments such as thinnings, or regeneration harvests such as shelterwood seed cuts and clearcuts.

Regardless of harvesting practice, residual stand conditions in all three states were analyzed with respect to total stocking, stocking of commercially desirable species, and stem quality, to determine whether it still was feasible to manage for sawtimber in the current rotation. In New York and West Virginia, only 20-27 percent of harvests had desirable residual conditions. In Pennsylvania, about half of the harvests produced desirable conditions. Because diameter-limit harvesting does not take future stand condition into account, the typically irregular spatial distribution of residual trees can affect new cohort development and restrict future management options. In 68 percent of the harvests surveyed in New York, cutting increased stocking variability by at least 1.5 times, i.e., the residual stand was more "patchy" than preharvest conditions. The distribution of regeneration also is irregular because the regeneration is concentrated in large gaps.

Effects of Diameter-Limit Cutting on Regeneration Composition and Density

In 1998 we revisited 86 of the sites from West Virginia's 1995 harvest assessment to measure regeneration characteristics as part of a collaborative effort by the West Virginia Sustainable Forestry Initiative Committee, West Virginia University, and the West Virginia Division of Forestry. Our objective was to create a model that uses stand-structure variables to predict regeneration density after harvesting. Forest ownerships ranged in size from 20 to 5,000 acres but sampling occurred in harvested stands ≤ 150 acres. Fifteen, circular plots (1/20 acre) were established randomly in each stand to measure trees ≥ 1.0 inch at 4.5 feet above the ground (d.b.h.) and record percent cover of all other woody and herbaceous vegetation and exposed rocks. Three milacre plots were nested within each larger plot to measure new seedlings and sprouts < 1.0 inch d.b.h. and record the number of browsed seedlings.

Table 1.—Seedling densities from 39 partial harvests (residual stocking < 50 percent) in West Virginia.

Species	Mean seedlings/ acre	Percent seedlings > 3 ft tall
American beech	236	30
White oak	270	4
Hickory	341	7
Black cherry	408	23
Ash	410	13
Chestnut oak	443	5
Birch	491	14
Red/Black oaks	682	14
Sugar maple	686	14
Yellow-poplar	953	18
Red maple	2736	5

Residual basal area averaged 58 ft^2/acre statewide (range: 0 to 152 ft^2/acre) and was dominated by red maple (*Acer rubrum*), yellow-poplar, and chestnut oak (*Quercus prinus*). Residual trees per acre were primarily red maple (17 percent), sugar maple (*Acer saccharum*) (16 percent), beech (*Fagus grandifolia*) (8 percent), yellow-poplar (6 percent), and hickory (*Carya* sp.) and black gum (*Nyssa sylvatica*) (5 percent each). Except for American beech and chestnut oak, over 90 percent of regeneration was classified as new seedlings. Forty percent of the harvests were considered "adequately stocked" under the criteria of 5,000 to 10,000 seedlings per acre and 85 percent of milacre plots stocked with one or more stems ≥ 1 foot tall (Trimble 1973). Red maple was the most abundant species statewide, followed by yellow- poplar, which had the most seedlings > 3 feet tall (Table 1).

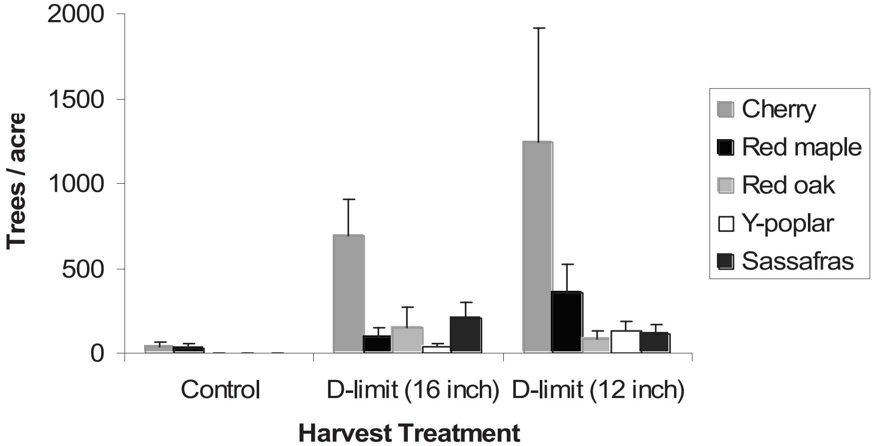

Figure 1.—Mean regeneration density (trees per acre) and species composition of seedlings > 20 inches tall 5 years after diameter-limit harvesting (uncut control, 16-inch diameter limit, 12-inch diameter limit) on the West Virginia University Forest.

Only 39 stands were included in the regression analyses for modeling regeneration density. These were the stands that had < 50 percent stocking after harvest and were classified previously (Fajvan et al. 1998) as having sufficient growing space for regeneration establishment. Data on stand structure from the 1/20-acre plots were averaged for each stand. Independent variables in the regression model included preharvest basal area, preharvest trees per acre, residual basal area in each of three height classes (1 to 20, 20 to 50, and > 50 feet), total residual basal area, residual trees per acre, and percent basal area removed. Percent browsed seedlings and percent cover of other woody and herbaceous vegetation and exposed rocks were averaged from the milacre plots for each stand and also included as variables. The dependent variable was the number of seedlings per acre ≥ 1 foot tall.

Multiple regression was used to determine which independent variables explained the greatest amount of variation in the data and should be included in the final model. An adjusted coefficient of determination was used to evaluate each model. The final model had an adjusted R^2 of 0.71 and included four variables that were most highly correlated with regeneration density:

$$Y = 7557.40 - 7.74*B1 - 44.25*B2 - 118.99*B3 + 67.10*B4$$

where:

Y = Seedlings/acre ≥ 1 foot tall (commercial species)
B1 = Residual trees/acre
B2 = Percent cover of herbs
B3 = Percent cover grass
B4 = Residual basal area/acre for trees 20 to 50 feet tall

There was a negative relationship of seedling density with total residual trees per acre and percent cover of herbs and grass. However, number of seedlings was positively correlated with residual basal area of trees 20 to 50 feet tall, which included most of the residual overstory. Most trees taller than 50 feet probably were removed in the harvests. The "high shade" produced by this canopy may have had a positive effect on shade-tolerant red maple, which dominated the regeneration. Also, at the time of this study, the regeneration had developed only for 4 to 5 years postharvest so perhaps insufficient time had elapsed for shading to have a negative effect on regeneration density.

Effects of Residual Trees on Regeneration Composition and Size

In 1993, four stands on the West Virginia University Forest in north-central West Virginia, were divided into three, 10-acre treatment blocks to receive a 12-inch diameter-limit harvest, a 16-inch diameter-limit harvest, or no harvest. The trees were about 60 years old. Stands were located on northern aspects, had average basal areas of 150 ft^2/acre, and were composed of yellow-poplar (50 percent of basal area), northern red oak (30 percent) and lesser amounts of red maple, black cherry and white oaks. Residual basal areas in the 12-inch harvest ranged from 10-30 ft2/acre and 30 to 60 ft^2/acre in the 16-inch harvest.

Regeneration composition was sampled prior to harvesting and annually for 5 years (Fig. 1), and again

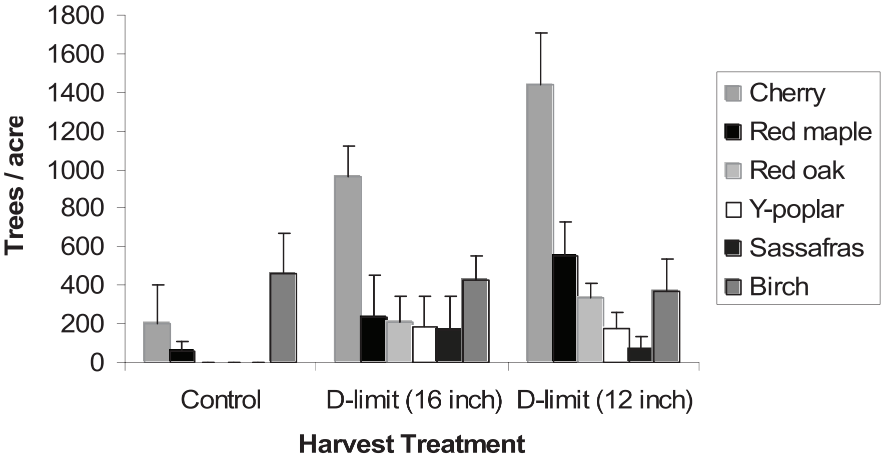

Figure 2.—Mean regeneration density (trees per acre) and species composition of saplings 1 to 5 inches d.b.h., 9 years after diameter-limit harvesting (uncut control, 16-inch diameter limit, 12-inch diameter limit) on the West Virginia University Forest.

Table 2.—Mean d.b.h., total height, live crown ratio, and crown projection areas of 130 residual trees measured 9 years after a 16-inch diameter limit harvest on the West Virginia University Forest (standard errors are in parenthesis).

Species	Number of trees	D.b.h.	Total height	Live crown ratio	Crown projection area
		inches	*feet*		*ft*^{2}
Chestnut oak	10	13.6 (0.4)	86.2 (2.4)	47.4 (2.1)	358.2 (39.3)
Red maple	40	10.2 (0.3)	61.0 (1.9)	57.7 (1.2)	341.1 (21.5)
Red/black oak	30	14.4 (0.4)	80.9 (2.2)	56.0 (1.5)	393.1 (27.4)
White oak	10	11.2 (0.5)	78.6 (2.8)	45.2 (2.0)	275.5 (35.4)
Yellow-poplar	40	14.5 (0.3)	82.7 (1.9)	52.0 (1.4)	252.3 (15.8)

at 9 years (Fig. 2). After 5 years, the 12-inch harvests had more regeneration > 3 feet tall than the 16-inch diameter limit (2,307 ± 612 vs. 1,273 ± 387 trees per acre, respectively). The uncut stands had less regeneration (293 ± 166) than the harvested sites. The 12-inch harvests had the lowest residual basal areas partly because 10 percent of the residual trees were destroyed during logging (Fajvan et al. 2002). These stands resembled clearcuts and had more sunlight and growing space to support higher regeneration densities than the 16-inch diameter-limit harvests. Regardless of treatment and time since harvest, black cherry was the most abundant species in the regeneration even though overstory black cherry represented only about 10 percent of the basal area before treatment. Black cherry also was the most abundant species of advance regeneration (see Fig. 1 Control) because it is not preferred as browse by white-tailed deer.

In 2003 we examined the effects of the residual trees in the 16-inch diameter-limit harvests on regeneration size and species composition to determine whether shading from the residual tree crowns affected the importance of shade-tolerant versus shade-intolerant species under tree crowns compared to the species composition of saplings in the gaps between crowns. A sample of 130 residual trees ranging in size from 7 to 17 inches d.b.h., were selected randomly from the four, 16-inch diameter-limit harvests proportional to their species' and size (diameter) representation in the stand (Table 2). Yellow-poplar and red maple were the most abundant species with average heights ranging from 61 to 86 feet. These 130 trees were used as plot centers, and saplings (1 to 5 inches d.b.h.) were sampled on 5-foot-wide transects arranged along 0, 90, 180 and 270 degree azimuths. Transects were variable in length because they extended 5 feet beyond the crown edge in their respective direction.

Because of the irregular spacing among residual trees, some crowns of the plot center trees overlapped other residual trees in the vicinity. Thus, saplings could be located under two or three overlapping crowns. Sapling total height, diameter, crown class (relative to associated saplings), and their distance from the plot center tree were measured. Sapling data also were categorized according to their location relative to residual tree crowns: 1) under the center tree 2), outside the crown of the center tree 3), under the center tree and an overlapping crown(s) and 4) outside the crown of center tree but under the crown(s) of adjacent trees.

Preliminary results indicated that of the 2,239 saplings sampled, black cherry was the most abundant species (importance value = 0.37) followed by red maple (importance value = 0.15). Red/black oaks, black birch and yellow-poplar each had importance values around 0.10. Twelve percent of the saplings were in the dominant/codominant crown classes with black cherry accounting for 45 percent of these followed by red maple and black birch about 13 percent each. The mean height of red maple (17.3 feet ± 0.5 foot) was greater than that of black birch (16.8 feet ± 0.5 foot) and black cherry (16.3 feet ± 0.3 foot). The average height of red/black oaks (8.2 feet ± 0.5foot) was about 50 percent less than that of these other species.

Saplings growing outside the crown of the center tree were taller (16.5 feet ± 0.3 foot) than those growing under its crown (15.3 feet ± 0.2 foot) or under its crown and another crown (14.6 feet ± 0.6 foot) or under the crowns of one or more other residual trees along the transect (14.5 feet ± 0.7 foot). Basal area and mean total heights of dominant/codominant saplings also were greater outside the center tree crown (57.3 ± 3.9 ft^2, 26.4 feet ± 0.6 foot) than under its crown (28.6 ± 2.4 ft^2, 24.7 feet ± 0.4 foot), or under its crown and another crown (12.7 ± 4.9 ft^2, 20.4 feet ± 1.3 foot), or under the crowns of other trees along the transect (53.1 ± 12.1 ft^2, 20.9 feet ± 1.02 foot).

Discussion

The studies discussed here expand our knowledge about the effects of partial cutting on stand structure, but this information does not alter our basic understanding of stand dynamics and minor disturbances. For example, Roach and Gingrich (1968) described residual stands resulting from past (partial) "overcutting" as having an "irregular crown canopy" with residual mature trees that generally "will deteriorate in quality" and with "desirable reproduction that will not develop properly." They observed that desirable (shade-tolerant) regeneration probably is present if stand stocking is below the C-level, but that it would eventually be overtopped by a less desirable "understory of tolerant brush." They recommended that the overstory be removed as soon as possible before residual tree quality deteriorated further and to favor growth of desirable (shade-intolerant) regeneration. Although timber markets have changed during the past 40 years, exploitative harvesting practices have not. The 1995 West Virginia harvest assessment and subsequent regeneration survey indicated that shade-intolerant, high-value species are favored removals in the harvests and that shade-tolerant maples and beech dominated the residual stands. Even though the tallest species of regeneration was shade-intolerant yellow-poplar 4 to 5 years after harvest, the density of red maple was nearly three times greater.

Another study on the West Virginia University Forest indicated that after clearcutting, red maple had slower height growth than yellow-poplar and black cherry but could grow as fast as red oak to eventually occupy a codominant crown position in the overstory with oak and poplar (Tift and Fajvan 1999). However, 9 years after diameter-limit cutting, our data suggest that partial overstory shade is more favorable to red maple height growth than to the growth of black cherry and yellow-poplar. Red/black oaks accounted for only 1 percent of the dominant/codominant stems and generally were overtopped by the other species. Of course factors such as intensity of deer browsing, annual seed production, site quality, and climate contribute to regeneration composition and development. For example, selective browsing by white-tailed deer rather than diameter-limit cutting was primarily responsible for the preponderance of black cherry on the West Virginia University Forest, even in the uncut stands. However, these variables were not measured in all of the studies discussed and are not reported here.

Acknowledgments

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Economics, Markets, and Diameter-Limit Cutting

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A successful financial outcome from forest management depends upon finding an approach that is relevant to the situation and pays an adequate return to the landowner. That means assessing the stand and forest conditions on a property, the requirements and constraints of the ownership, the markets for products from the land, and the social framework that tempers the management options. Managers must also consider the operational costs of a program, the opportunities for generating revenues, and how these balance in the short and long run with respect to the management objectives. Stand treatments must sustain a desirable set of conditions on the ground, and insure a continuing flow of values consistent with the management objectives.

Operational conditions often make classic silvicultural difficult or impractical. Instead, foresters must commonly adapt to several realities that constrain practical management. This includes the potential of a site, the species mix and the relative value of each one, the ages and sizes of trees in a stand, the vigor and quality of the growing stock, and the location and accessibility. In addition, the size of an ownership and its component stands affect the extent of yearly silvicultural operations that forestry can sustain, and the potential to annually generate revenues and other values that repay costs of the operations and provide a profit to the landowner.

Landowners commonly set a limit on the risks they accept for investments in ownership, management, and holding growing stock on the land. So potential dangers like losses to blowdown, ice storms, outbreaks of harmful insects, and fire all influence when owners want to harvest trees from their lands, and how much residual value they willingly leave in a stand. Further, they may have expectations for realizing regular returns on their investments, both in the amount of revenues required annually and the consistency of yields through time.

Markets may ultimately control the options available, and particularly affect treatments that require cutting of small and low-grade trees. In some areas, managers can merchandise non-timber benefits as recreation leases or use fees, or they might offer conservation easements that help cover costs of taxes and other overhead expenditures. Those non-timber revenues might temper the balance between costs and returns from timber operations.

Since markets do not remain static through time, managers must regularly track price fluctuations, including the difference between species. An appropriate long-term strategy keeps the options open by not over-cutting all the most valuable ones in any short period of time. To maximize the revenue potential, managers must also balance operating costs per unit of volume harvested against the price gain from growing trees to large sizes. The revenue curve shows that trees generally increase in value with size, but with net value eventually dropping due to rising operating costs. The peak of that curve suggests a size for financial maturity based on cash flow.

To contain operating costs, landowners must work with contractors to find a harvesting system fitted to the site conditions, the total harvestable volume, and the size and species of trees planned for removal. Working with contractors to communicate clear outcomes for each operation can save on marking and layout costs. Regular performance reviews and frequent communication with the harvesting contractor insure compliance at the harvesting site. Transportation costs may importantly affect stumpage value and revenues. Having a good network of logging roads or good access to well-maintained public roads also helps to reduce the operating costs. Managers must also take account of timber quality and harvested volume, using the higher value timber as an incentive for operating under the more challenging conditions. Further, offering fairly consistent harvestable volumes through all seasons provides continuity for the harvesting contractor and insures year-round operations on our lands.

The diameter often proves the most determinant factor of sawlog quality. Large-diameter logs yield greater amounts of high quality lumber and allow more options in milling and later processing. Appropriate bucking and sorting are also critical in optimizing value recovery from those pieces. Huber Resources controls this by transporting tree-length logs to a concentration yard where we buck the trees into shorter logs and separate them by product class. We also lay out the sawlogs in rows and periodically invite buyers to submit bids on individual ones. That has improved revenues. Other landowners might realize similar gains by working with harvesting contractors who sort logs by product to increase their own revenues. That should improve the stumpage prices they offer.

Besides keeping track of cash flow, managers can use a variety of return-on-investment analyses to compare the long-term potential of different management options. They should account for changes in available volume and the component quality, the demands of markets and effects on the price of different species and roundwood products, changes in harvesting technology and the resultant costs, and the rate-of-return requirements of a landowner. How these factors come together importantly tempers the outcome, with the results depending both on the cutting strategy and the ownership framework.

Each owner has a unique set of financial requirements and reasons for owning a forest. That challenges foresters to clearly understand the objectives and find creative ways to adjust to the situation as it changes through time. Having trees of the larger diameters and good bole quality enhances the revenue potential. Yet cutting strategies that repeatedly remove only the large trees and leave the small ones have not historically provided consistent amounts of volume over the long run, and that reduces the chances of insuring a steady stream of revenues into the future. Even so, silviculture research has not effectively addressed the conflict between demands for short- vs. long-term profitability, nor offered solutions for practical management. That challenges foresters to find appropriate strategies for providing sustainable returns on the investment of ownership and management.

Genetic Effects of Diameter-Limit Cutting

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The long-term health and productivity of forests is influenced by genetic diversity that enhances resiliency in response to environmental change. Loss of specific genes and a reduction of overall genetic diversity could affect productivity, ecosystem stability, long-term survival, and evolution. Harvesting trees removes genes from a forest. The effect of this removal depends on the: 1. heritability of traits, especially growth; 2. inherent variability of a site; 3. age structure of a stand; 4. intensity and timing of the manipulations; 5. amount of advance regeneration; 6. size and degree of isolation of the stand; 7. original level of genetic diversity; and 8. number and genetic make-up of residual trees. It is important to consider the short- and long-term impacts on the quality and sustainability of the residual stand following harvesting.

The genetic diversity of the residual stand following harvest can be changed in several ways. Through selection of certain phenotypes (outward appearance of individual) there could be a loss of or change in genetic diversity if there is a strong phenotype-genotype relationship or growth-genetic diversity relationship. Also, the genetic diversity of a stand could be compromised if there is a large reduction in population size, which might result in increased inbreeding or a poorly adapted residual stand.

One way that we have assessed the genetic implications of diameter-limit cutting was by simulating the effect of different cutting strategies on red spruce populations of known genetic diversity. Selecting 25%, 50% and 75% of trees to remove at random resulted in the loss of only one allele (one of multiple forms of a gene), and no significant change in heterozygosity (a measure of the proportion of the genes that are genetically variable). Selecting the fastest growing trees to be removed (based on basal area increment) led to a loss of 2, 4 and 15 alleles, respectively, for the three cutting intensities. Only at the highest removal intensity (75% of fastest trees removed) was there a significant reduction in heterozygosity.

In another study we assessed the genetics of a 300-tree white pine population, mapped the tree location and measured several tree age and growth characteristics, resulting a genetically-mapped forest. The stand had three age classes, with the oldest comprised mainly of wolf trees. Heterozygosity increased with age, except for the old wolf trees. Data also show a tendency for trees of poorer crown positions to have more rare alleles. In this study, a simulated harvest indicated that cutting the old trees (≥29 inches dbh) reduced the genetic diversity in the stand. Cutting mostly overtopped trees in this case study decreased the number of rare alleles.

We also evaluated the influence of long-term silvicultural selection on the genetic structure of an eastern hemlock forest at the Penobscot Experimental Forest in Maine. Plots in this forest received one of the following three treatments: 1) selection cuts in which small and poor-formed trees were preferentially removed in 1957 and 1977, 2) diameter-limit cuts in which trees 24 cm in diameter and larger were removed in 1952, 1973, and 1994, or 3) no harvesting (an unmanaged control). Because of an association between the occurrence of rare alleles and tree phenotypes, phenotypically based tree removals were associated with a shift in allelic frequency. Where smaller trees with inferior phenotypes were preferentially removed (selection cut), the number of rare alleles was lower and estimates of future genetic potential were lower relative to the control. Because of the theoretical long-term evolutionary benefit of unique gene forms, the loss of rare alleles could diminish the potential of populations to adapt to and survive ongoing environmental change. In contrast, trees in the diameter-limit cuts had fewer rare alleles, more low-frequency alleles, more lost alleles and interestingly were higher in heterozygosity. It appears that the increase in heterozygosity of trees in the diameter-limit cut was due to an increase in frequency of alleles that were rare in the control stand, thus increasing low-frequency alleles and increasing heterozygosity. However, productivity was low in this stand where the frequency of characteristically rare alleles was artificially amplified.

Differences between the three management strategies are evident in the effects on rare alleles. Rare alleles are generally thought to have deleterious effects on the growth and overall fitness of a tree. So, cutting smaller trees may remove some of these undesirable alleles from a population, and selection system cutting in an uneven-aged stand may have positive short-term effects on growth. This will presumably improve the short-term fitness of the stand as well. Yet the rare alleles reduced by selection system cutting and amplified by the diameter-limit cut may be vital to long-term adaptation and evolution of future generations. Findings from other researchers have found similar increases in rare alleles associated with poor quality, slow growing phenotypes.

Findings in our work that are supported by work of other researchers for a variety of conifer species have shown that limited removal of the largest or fastest-growing trees does not appear to significantly alter the population genetics. Yet repeated heavy removal of larger diameter trees may affect the residual stand. Findings suggest that the smallest and slowest growing trees in a population may contain high frequencies of alleles that are rare in the whole population. These individuals should not be left as the only residual trees. It appears that managers should leave trees of a range of sizes to insure that regenerating offspring have the maximum number of alleles. Maintaining this genetic diversity may be critical to the long-term survival and adaptability of a species.

Ethics Considerations with Diameter-Limit Cutting

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Abstract

High grading is a poor management practice by definition. It has serious long-term implications to stand structure and function. The use of this management technique creates some ethical dilemmas. By examining the codes of ethics for the Forest Stewards Guild, Association of Consulting Foresters, and Society of American Foresters, only the Society of American Foresters has a code that attempts to balance landowner's rights and an environmental ethic. These seemingly two opposed views can create an ethics problem, but the forester must observe due diligence to keep from an ethics violation. Conversely, ethics violation charges are very difficult to prove in the case of diameter-limit cutting.

Introduction

The views of this paper are my own and may not represent any organization or affiliation that I have. This statement must be made to insure that the words and ideas do not have more weight or importance than my opinion. As someone who is interested in ethics and its practical application, this subject provides a fascinating case study. In fact, others actually have already rendered opinions on this topic (Lockhart and Nyland 2004). I propose to look at this problem in the light of three Codes of Ethics. The purpose of this paper is to provide the reader with a practical approach to determine when diameter-limit cutting may be a violation of ethics, how to be protected if placed in a dilemma, and what information is needed to bring charges against an individual who may have violated a code of ethics.

Diameter-Limit Cutting and High Grading

This conference has already discussed the implications of high grading and diameter limit cutting in eastern hardwoods. However, Reynolds (1980) found in the 1950s that in loblolly and shortleaf pine that if the diameter limit was set high enough (>18 inches) and the poor material was removed from the smaller classes high grading did not result. I suspect that hardwood stands may respond similarly, but limiting diameter size is unknown. Diameter limit cutting in the strictest sense may not necessarily be high grading. The Dictionary of Forestry (Helms 1998) defines high grading as: *the removal of the most commercial valuable trees (high-grade trees), often leaving a residual stand composed of trees of poor condition or species composition …high grading may have both genetic implications …and long term economic or stand health implications.* Is high grading bad? The answer is yes in light of the long-term implications of the practice. It is not sustainable; the property owner's "forest factory" is compromised so that all products of the forest may be affected. The "forest factory" concept is that the forest is a capital investment that produces tangible and intangible goods and services. The quandary is that one of the goods produced by the factory is the factory itself. By strict definition, high grading is bad because it decreases the present and future value of both the factory and products derived from that factory. If diameter limit cutting equates to high grading, then that practice is bad. Defining high grading in the field may be more difficult. A couple of questions come to mind. Does removal of shelterwood/seed tree overstory constitute diameter limit cutting or high grading? Does leaving wildlife trees be defined as high grading? The clear difference in high grading and using diameter limit cutting as a tool is the desired outcome. If the objectives are set, then the result of a practice is clearly evident. However, rationalizations for bad practices are all too often used instead of using forethought to a desired outcome. Very rarely do well-written management plans result in high grading.

Definition of Ethics and Codes of Ethics

Everybody knows what ethics are but they are difficult to describe. Lammi (1968) stated that ethics is the relationship of conduct with the goals of a particular profession or society as a whole. If ethical, this conduct contributes to the goals of the profession and society. Unethical practice hinders the achievement of the goals. Chapman (1947) distinguished religion from ethics by stating that religious tenets relate to human life as a whole while ethics relate to professional conduct. Lammi (1968) separated ethics from morals and morality on the basis of whether the rules and practices relate to society as a whole or relates to the activities of a particular group or profession. A profession has specific codes of behavior that members of that profession must conform in order to be allowed to practice. A stated code of ethics and adherence to that code is the mark of a true profession. One of the main purposes of professional societies is to codify these rules of ethics that govern the behavior of its members.

There are three main organizations of which professional foresters may be members that have a code of ethics and violations may occur: Society of American Foresters (SAF), Association of Consulting Foresters (ACF), and Forest Stewards Guild (FSG). Each has a list of their code of ethics on their respective website. The ethics of workmanship, conflicts of interest, employee/employer relations, public interactions and discourse, credit, and confidentiality all are almost identical for SAF and ACF. The Code of Ethics of the ACF is more client-centered and does not have a land ethic. The ACF code is very good at outlining business behavior and interactions. The FSG is eco-centric and has a very strong statement about land stewardship. There are no statements on professional or business interactions beyond the statements on forest value.

One of the purposes of a code of ethics is to inspire members to higher standard of behavior. This is certainly evident in the preamble of the SAF Code of Ethics. The preamble sets the tone for the Principles and Pledges. The theme is the balancing of long-term values of the forest, the environmental ethic, and the property rights of the landowner. It specifically states that landowners have responsibility to the long-term value of forestland. This dichotomy was spelled out by Lammi (1968) when he stated that ethics has a goal of freedom and responsibility. He stated that Chapman (1924) had argued the same point in his discourse that a forester's concept of conservation rejected the responsibilities of the extremists who advocate low level of resource use (preservationists) or advocate immediate monetary rewards (despoilers). The ACF code and preamble is an excellent standard for business and professional conduct. The first code states: *ACF Consulting Foresters will utilize their knowledge and skill for the benefit of society*. If societal benefits include values from the forest, the first statement of this code could be interpreted as a land ethic or at least a sustainable value ethic. The principles of FSG are explicitly forest centered and nature oriented. If landowner objectives conflict with these principles, the forester should *disassociate*.

In the light of diameter limit cutting and high grading, where does each of these organizations stand? Obviously, anything that would diminish the values of the forest would be contrary to the principles of the FSG and the forester should not continue. For the ACF, if the landowner's rights are paramount and the forester must follow the lead of the employer. For the purposes of this discussion, these organizations have different but "cut and dry" view of this topic. The Code of Ethics of the Society of American Foresters creates an ethical dilemma because it has both a landowner's rights pledge and a land ethic. The problem is balancing the two principles that seem to be opposed.

SAF Code of Ethics and High Grading

Is high grading contrary to the SAF Code of Ethics? Principles 1 and 2 of the code deal with high grading issue. They are as follows:

1. Foresters have a responsibility to manage land for both current and future generations. We pledge to practice and advocate management that will maintain the long-term capacity of the land to provide the variety of materials, uses, and values desired by landowners and society.

2. Society must respect forest landowners' rights and correspondingly, landowners have a land stewardship responsibility to society. We pledge to practice and advocate forest management in accordance with landowner objectives and professional standards, and to advise landowners of the consequences of deviating from such standards.

As foresters, we have an obligation to practice and advocate methods that result in long-term worth and productivity of the forests. We are ethically bound to place this at the forefront of our practices, but there is another side of the coin. The forest landowner has rights to the land they own especially to extract value from the property. In fact, continuing to produce acceptable rates of return from forestry investments will keep land in forests instead of alternative uses. The art of forestry is melding the landowner objectives and values with the current conditions of the forest stands that result in long term worth and productivity.

The conflict with the code can occur with two types of behaviors: the first is to knowingly high grade without explaining the consequences to the landowner or robbing the landowner of the value of his lands and the second is the landowner is only interested in immediate income. The first behavior not only violates Principles1 and 2 but also blatantly violates Principles 5 and 6 by not openly communicating with the client and by being dishonest. The second behavior is much more common and puts the forester in the middle of the dilemma. The landowner may have valid reasons for wanting the money now and he has the right to it. The forester has two options at this point; walk away or explain to the landowner the consequences of these actions. If the forester continues working for the landowner after explaining the consequences, he/she has fulfilled the obligation to the Code of Ethics, but the forester must continue to be an advocate of good silviculture throughout the process.

The procedures for ethics charges against members of the Society of American Foresters are found in the SAF By-Laws. This document can be found on the web site (www.safnet.org). Charges are instigated by a letter describing the violations with evidence to support the violations to the President of SAF. This letter must have at least two signatures and the charges can be made by anyone. One does not have to be a member to file charges. This letter starts a process of investigation that leads to acquittal or disciplinary action. The process is designed to protect the rights of the accused. The evidence needed to convict a member of unethical conduct for high grading would require considerable information. The intent of the landowner must be established, the forester's behavior must be documented, and the outcome of the action must be proven. If one of these three points were to fail, the accused would be acquitted.

Conversely, the foresters must protect themselves when placed in a compromised condition. Foresters must show due diligence. Copies of written correspondence on advice to the landowner and management plans are excellent pieces of evidence to demonstrate the forester's intent. The demonstration of forethought and not rationalization will prove to be adequate to prevent conviction on an ethical charge.

One of the best pieces of advice on how to prevent ethics violations was stated by Patterson (1984) and modified by Irland (2001). The four simple questions that one must ask are:

- What if everybody did it?
- Would I want to read about it in the paper tomorrow?
- What will it look like tomorrow?
- Would I be comfortable explaining this to my 12-year-old?

By examining these questions, most ethical problems will be solved. In fact, we should be inspired to act in a more ethical manner than stated in the code. By doing this, we should be a better profession.

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Rehabilitating Cutover Stands: Some Ideas to Ponder

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Here's The Issue

Landowners who have cutover stands usually want to rehabilitate them at no out-of-pocket cost. That always proves challenging. In fact, rehabilitation must start with the investment of assessing conditions that diameter-limit and other exploitative cuttings created. Then managers must identify ways to improve the situation, and finally select an alternative that minimizes additional cash outlays in the process. At best, they often settle on a least-cost approach, hoping it will return a stand to profitability in a reasonable time.

Yet landowners and their managers face a harsh reality. Having allowed or encouraged diameter-limit cutting, they already incurred a heavy cost in:

- production opportunities lost due to poor stocking after the heavy cutting
- reduced quality and vigor of the residual trees
- lessened revenues due to prior cutting of the most desirable species

As a result, the rehabilitation commonly becomes a last resort for salvaging a hopeless situation, with little promise for turning an immediate profit. It often requires considerable investments under the worst of situations.

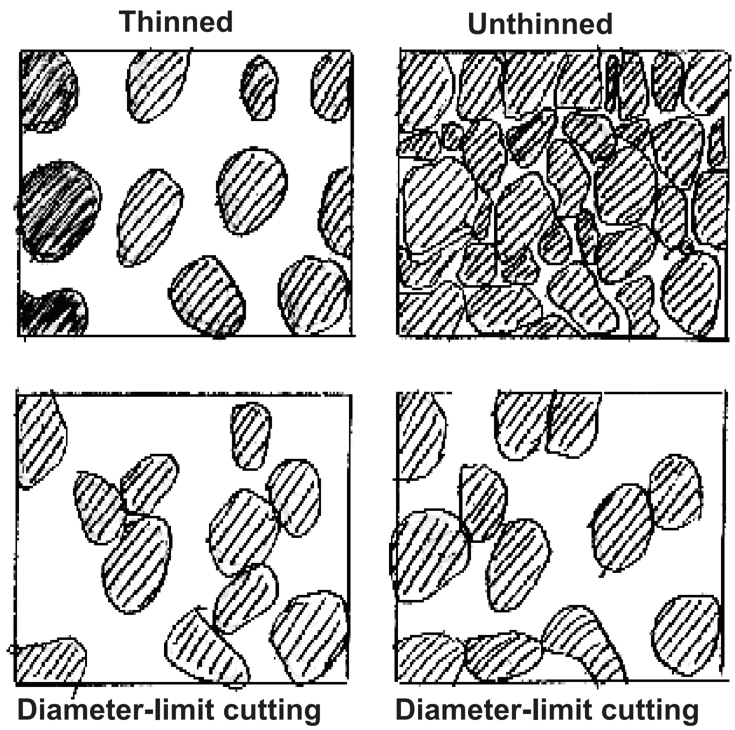

Figure 1.—Common difference in canopy cover between even-aged stands after thinning and a diameter-limit cutting (adapted from Smith 1986).

The Legacy

Diameter-limit cutting usually leaves stands with a patchy distribution of residual trees (Fig. 1), including crowded conditions in some areas and sizable openings or only widely spaced trees in others (Nyland 2002). In fact, assessments in New York indicated that the variability in basal area (reflected by the coefficient of variation) increased by at least 1.75 to 2.0 times due to diameter-limit cutting, but no more than 1.5 times under silviculture. As a consequence, diameter-limit cutting results in incomplete and ineffective site utilization, with the dispersion of under-stocked and over-stocked places dependent upon the initial placement of trees larger than the threshold cutting diameter. Within uneven-aged communities, diameter-limit cutting often removes all or most the age classes that had grown to merchantable sizes, leaving the saplings and poles. Some cuttings may also leave the cull or low-value sawtimber stems. Further, it does no tending of the residual trees to enhance stand quality and vigor. Commonly, a residual uneven-aged stand has no more than 60-70 ft^2/ac of basal area, distributed in a patchy fashion. For even-aged stands, diameter-limit cutting has an even more devastating effect. It removes all the marketable trees, leaving trees of poor crown position, vigor, and quality. In addition, diameter-limit cutting in even-aged stands often leaves no more than 50-60 ft^2/ac of basal area after even a single entry. The stands also have a patchy distribution of residuals.

To make conditions worse, when landowners allow diameter-limit cutting they often signal a lack of interest in controlling the logging process as well, and many times the operation leaves large numbers of damaged or destroyed trees. Injuries to the main stem reduce the value, and particularly from wounds to the butt log. Loss of broken off or bent over trees creates additional places of low residual density, further reducing the production potential of the stand. Logging on saturated soil also causes deep rutting, severing the roots of trailside trees, opening entry courts for fungi, and reducing the carbohydrate storage capacity of the affected trees (Shigo 1985). These injuries often become manifest as crown dieback or decline during later periods of moisture stress. So managers must assess wounds to the bole and crown of residual trees, as well as damage to the root systems, when they search for the acceptable growing stock and make their judgment about continuing the management of a cutover stand.

Altogether then, landowners who want to rehabilitate cutover stands face some important challenges, particularly after two or more diameter-limit and other selective cuttings. These include (after Nyland 2003):

- few trees of good vigor and high quality remain, limiting the future potential for volume and value growth.
- the stand often has a patchy distribution of residual trees, resulting in incomplete site utilization and little control over understory development.
- limited usable volume remains, making a rehabilitation cutting commercially marginal or infeasible.
- a scarcity of large trees limits seed production, complicating attempts to establish a new cohort in stands lacking adequate advance regeneration.
- where past cutting proved dysgenic, the effect may carry over into new age classes that derive from the poor residual trees.
- interfering plants may dominate the understory, particularly in the more open areas, further challenging chances to regenerate new seedlings across the stand.

These aftermath conditions translate into production opportunities lost, and diminish the potential for profitable management in the years ahead. Under the worse of circumstances, they may require considerable investment to correct. Even in the least severe cases, a rehabilitation treatment will not necessarily restore a stand to its previous state. But it will set the stage for its gradual recovery to a more sustainable condition.

A Basic Strategy

Rehabilitation of cutover stands requires four basic measures:

1. even the spacing between residual trees by removing the poorest ones;
2. concentrate the growth potential onto trees of acceptable quality, or the potential to grow into ones of reasonable value;
3. regenerate a new cohort to fill the empty space; and
4. control interference to enhance regeneration success.

The need for each component differs between stands, forcing managers to carefully assess the situation before prescribing any rehabilitation treatment for a stand. In making the appraisal, they must look at the distribution and abundance of acceptable growing stock trees, usually by watching for ones having these characteristics (after Smith 1995, Nyland 2003):

- at least a lower codominant within the original even-aged stand, or within a cohort of an uneven-aged community;
- at least 20-25% of the height with live branches;
- no epicormic branches on the lower bole;
- no holes or fruiting bodies on the main stem;
- less than 25% of the major branches dead or dying; and
- not leaning more than 10° off vertical, and no heavy forking.

In addition, preferable trees have live branches growing from all sides of the main stem (balanced crowns), and lack signs of structural weakness along the main stem or in the crown. The best ones also have few grading defects in the butt log, or a potential to heal over old branch scars with sufficient wood to yield high quality boards from the outer faces. In the final analysis, the alternatives depend upon the number and distribution of these acceptable trees, and the degree that they will increase in volume and value in the foreseeable future.

Excluding stands suited to management with fairly traditional silviculture, the rehabilitation will likely deal with two basic conditions:

1. stands with some good residual trees, but at a low density; and
2. stands of limited promise

Rehabilitation for these will have some common elements, but the latter group will require more effort. Also, the financial requirements will differ appreciably.

Stands With Good Residuals

These stands lack sufficient acceptable trees for full site utilization, but have some worth growing to larger sizes as future sawtimber or pulpwood. The rehabilitation objectives include:

- retaining the best trees for future development; and
- creating a new age class beneath them.

Implementation would include reducing the residuals to extra wide spacing, concentrating the growth potential onto these few (the best) uniformly spaced trees, releasing any desirable advance regeneration, and establishing regeneration to fill the empty spaces.

Note that an even-aged northern hardwood stand at 40% residual relative density should develop sufficiently for full site utilization within a 15-year period (Leak et al. 1969, Roach and Gingrich 1968), given uniform spacing among the residuals. But some cutover stands have insufficient acceptable growing stock to make that option appropriate. The patchy distribution of residuals also precludes reasonable site occupancy if left alone. Instead, conversion to a two-aged arrangement might prove suitable for the long run. In that case, if the long-term plan calls for each age class to occupy one-half of the growing space, and for keeping the older ones until they reach 16 to 18 in. dbh (with a crown radius of about 15 ft), the ideal post-rehabilitation stand should have residual trees at a 40-ft spacing (about 30 trees/ac). That might leave so little basal area that in some localities landowners must obtain a permit for the heavy cutting. Then they could increase residual stocking above the jurisdictional threshold by leaving some marginal trees. They would return to remove these poor ones when stocking of the acceptable ones (including the new cohort) passes the critical jurisdictional level.

For cutover uneven-aged stands having no or only a few acceptable sawtimber trees, the cut might leave 50-60 ft^2/ac, with 2/3 of the basal area in poles (≥6 in. dbh) left at uniform spacing, and a disproportionate number of ones >8 in. dbh to promote their early movement into sawtimber. This strategy will brighten the ground and facilitate development of any advance regeneration. If stands still have a nominal component of acceptable sawtimber trees, then the treatment should make the spacing uniform among residuals and begin to balance the age classes by retaining trees of all sizes. An ideal stand with some acceptable sawtimber trees would have at least 55 ft^2/ac of residual basal area, with:

- 20% in trees <6 in. dbh;
- 35% in trees 6-11 in. dbh; and
- 50% in trees of sawtimber size.

This low stocking would also brighten the understory considerably, and promote the rapid development of advance regeneration. Also, a stand at that stocking would support another entry in about 25 yrs, or 5 yrs sooner for each additional 10 ft^2 of residual growing stock in large poles and sawtimber (after Hansen and Nyland 1984).

Where a cutover even- or uneven-aged stand has appropriate advance seedlings, these cutting treatments will promote their growth. Further, seed from the residual sawtimber trees will help fortify the stocking of regeneration. Otherwise, landowners may need to add reinforcement planting to compensate for the shortage of regeneration, particularly in cases lacking a good in-stand seed source. In addition, they must control interfering understory vegetation where it occurs at a critical density (e.g., see Bohn and Nyland 2003). Yet if done by broadcast methods (e.g., mistblowing an appropriate herbicide) the site preparation will also eliminate the advance regeneration. So managers must have a plan to reestablish the new age class by some deliberate means.

Stands of Little Promise

Some cutover stands (particularly after two diameter-limit cuts) have too few acceptable trees, and the residuals often have such low vigor that they also produce little seed. In other cases, landowners must remove all or most of the ones present to make the rehabilitation cutting commercially feasible. In both cases, the treatment should remove the low-grade remnants, and create a replacement age class. Stands in this condition often also lack advance regeneration and have important amounts of interfering understory plants. So the rehabilitation must:

1. clean off the cull and low-grade trees;
2. leave any suitable ones that might serve as a seed source, or provide some future revenues;
3. do site preparation to reduce the understory interference; and
4. plant the voids with new trees.

Mechanized harvesting and access to a biomass or pulpwood market may make the cutting cost-neutral: providing sufficient revenues to pay costs of other aspects of the rehabilitation. In stands with only a low volume to harvest, landowners may need to trade the stumpage in return for getting the cutting done. That would reduce their investments to the cost of site preparation and any planting. Where stands lack advance regeneration or have only scattered seedlings, conversion to conifers may seem best, but at a real cost. So recovering sufficient volume for a commercial sale may prove essential in making the entire rehabilitaton cost-neutral.

The Importance of Action

In severe cases where landowners will not commit to investing in these operations, they could wait until a stand grows sufficient volume to pay costs of the treatments. In some cases, landowners have opted to dispose of the property instead. Yet the latter of these alternatives just abdicates responsibility for the past and passes the problem to someone else. Hopefully, landowners will prefer to do something to improve the situation, so they can return their cutover stands to a more desirable condition.

Altogether, rehabilitation requires a commitment to reverse the past and initiate a program of sustainable forestry. In the long run, landowners will find better opportunities by practicing silviculture in the first place. Yet where they must embark on a rehabilitation program, they might choose among these options (Nyland 2003):

1. Look for trees with reasonably well-developed and balanced crowns[1], good stem form, a marketable quality, and a potential to produce seed.
2. Keep sufficient numbers for future management, and cut the rest.
3. For uneven-aged stands, retain good trees of different sizes, interspersed throughout.
4. Remove just enough volume for a commercial harvesting operation, and to take out the unacceptable trees.
5. Leave uniform spacing, independent of the number kept for the future.
6. Deliberately establish a new age class, unless the overstory trees will fully occupy the site as they develop.
7. Reduce any interfering vegetation to insure regeneration success.

In essence, they should leave as many of the best trees as circumstances permit, keep them at uniform spacing, and regenerate a new age class to fill voids between and beneath the residuals. This means carefully evaluating the options, working out the costs with reference to the potential revenues, and guiding the decision-making to the best possible end result.

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Contains nine papers presented at the conference on diameter-limit cutting in northeastern forests on May 23-24, 2005, at the University of Massachusetts at Amherst.

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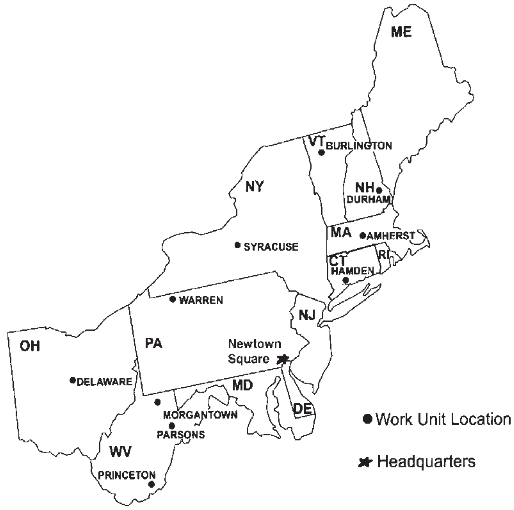

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