The Conversion of Even-Aged Stands to Uneven-Aged Structure in Southern New England

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ABSTRACT: *Partial cutting is common in mature even-aged stands in southern New England because the level of disturbance associated with even-aged regeneration methods is unacceptable to many private owners of small forest properties. This cutting often consists of high-grading, but foresters seeking an alternative generally turn to the selection method to begin the conversion of these stands to uneven-aged structure. However, the single-tree or small-group selection methods used may produce long-term results that are similar to high-grading in shifting stand composition toward shade tolerant species (many of which have low timber value). A review was made of the extensive research on the use of the selection method in northern New England and central Appalachian forest types, as well as of the limited research in the southern New England transition hardwood-white pine (*Pinus strobus*)-hemlock (*Tsuga canadensis*) type. Recent management experience in a Massachusetts public watershed forest was also reviewed. These provide general guidelines for using selection cutting in the region to regenerate species of a wide range in shade tolerance: (a) use patch selection (rather than single-tree or group selection) with a minimum patch size of 0.3 ac, and with understory as well as overstory trees removed in the patches; (b) use area control (proportion of stand to be harvested) rather than a target diameter distribution (*q*-value or other method) to regulate the stand cutting level. This approach is likely to be effective in meeting regeneration goals and in being logistically feasible, given the intensity of management possible on most of these properties. North. J. Appl. For. 20(3):109–116.*

Key Words: Selection method, high-grading, patch selection, group selection.

Interest in converting stands from even-aged to uneven-aged structure is one aspect of a worldwide trend toward using silvicultural systems that mimic natural forest disturbance processes or are at least perceived to be "natural" (O'Hara 2001). The ecological and aesthetic effects of this conversion in age structure are greatest in regions where the landscape is presently dominated by plantation monocultures. In these cases, the use of uneven-aged silvicultural methods that rely on natural regeneration both increases tree species diversity and creates a more complex age structure at the stand level. Interest in this approach also exists in southern New England, where plantations are rare and the stands that presently dominate the landscape already have high tree species diversity but tend to be even-aged, dating from heavy cuttings 70 to 110 yr ago and from hurricane destruction of stands in 1938 (Seymour 1995). In this case, much of the interest is based on a desire to minimize disturbance to the forest while deriving moderate levels of income from timber, rather than on any dissatisfaction with the current forest landscape.

This article focuses on the question of how to begin the process of age structure conversion in the forests of southern New England. This region, consisting of Connecticut, Massachusetts, Rhode Island, and the southern parts of New Hampshire and Maine, is defined ecologically as a transition between the northern hardwood type to the north and the central hardwood type to the south (Westveld 1956). Two important conifer species—white pine (*Pinus strobus*) and hemlock (*Tsuga canadensis*) also occur with the transition hardwoods throughout the region. Using the forest classification system of Irland (1999) based on ownership characteristics, most of the region is considered "rural forest" in which the former farm-and-woodlot landscape has become heavily forested, with farm ownership parcels being subdivided and purchased by private owners who are not farmers. Forests

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close to major cities (primarily in the coastal areas) are classified as "suburban forest," in which ownerships have become even smaller, and urban development has fragmented the forest habitat. Overall, the forestland ownership by area in the region is approximately 85% nonindustrial private, 14% public, and only 1% forest industry (Irland 1999).

Many private landowners in the region live on or very close to their forest property, and their principal reasons for owning their land are privacy, rural landscape beauty, recreation, and firewood for home use (Rickenbach et al. 1998). Many also have a strong general interest in conservation goals, such as protection of rare or threatened wildlife species, and recognize the importance of their land for wildlife habitat. Landowners who have timber harvested on their land often have modest income requirements—they seek enough either to pay for costs of owning the land or for occasional extra expenses, or to allow the land to be enrolled in a property tax abatement program based on forest management. Many desire to achieve these goals with a minimum of cutting, which leads consulting foresters to rely on the selection method. The heavier cutting required by even-aged systems and the resulting early successional vegetation are associated visually with clearing for development and with vegetation beneath powerlines and on abandoned land and are therefore considered undesirable by landowners of the region (Askins 2001, Gobster 2001). This reaction against severe disturbance appears to be more important that detailed analyses of habitat requirements; for example, many wildlife species in the region are declining because of the scarcity of large blocks of early successional forest, which are best produced by even-aged methods (Thompson and DeGraaf 2001). Management of public forests is more likely to involve even-aged silviculture, but many public land managers are also grappling with the issue of developing greater structural diversity for watershed protection or habitat for late-successional species, and are also considering uneven-aged management as a possibility.

The question of how to apply the selection method to convert even-aged stands to uneven-aged structure is of considerable importance at present because the short-term objectives of private landowners in many cases are being met with the use of diameter-limit cutting or high-grading, since these provide income through the harvest of a small number of trees. In these cases, landowners are either unaware of the long-term implications of these cutting practices or are unconcerned about them.

The objectives of this article are to review research on two main silvicultural problems that arise when planning for the use of the selection method in stands that are currently even-aged: assuring the establishment of regeneration in certain portions of the stand, and regulating the overall level of cutting within the stand. Specifically, the questions to be addressed are:

1. What size of canopy openings and what cutting intensity within the openings are necessary to obtain regeneration of high tree species diversity that includes the desired species?
2. How should the level of cutting be controlled: by the use of target diameter distributions, by allocating a portion of the stand area to be harvested in each cutting, or by some combination of the two?

Very few studies addressing these questions have been carried out in the transition hardwoods forest type. However, detailed studies of the application of the selection method to even-aged stands have been carried out in northern hardwood forests in northern New England, and in central Appalachian hardwoods to the south, primarily on experimental forests of the USDA Forest Service (studies cited below). Results from these studies in adjacent regions are reviewed and applied to southern New England forests with care taken to account for differences in species composition among the regions. Then, an example of an operational program to create uneven-aged forest structure on a public watershed forest in central Massachusetts is examined to gain insight from that practical experience in dealing with these two issues.

Forest Type and Current Management Situation

Southern New England forests vary in composition from the northern hardwood type in higher elevations to central hardwoods near the coast, with most falling into the transition hardwood type. Stands characteristically have 5 to 10 tree species that each make up a substantial portion of stand basal area. Because of the marked differences among species in growth characteristics, even-aged stands generally form stratified canopies. The upper canopy of young stands is dominated by the fast-growing pioneer species, including pin cherry (*Prunus pensylvanica*), aspens (*Populus* sp.), paper birch (*Betula papyrifera*), and gray birch (*Betula populifolia*), but this canopy is short-lived, beginning to break up in 15 to 40 yr. In older stands, some combination of red oak (*Quercus rubra*), black oak (*Q. velutina*), white oak (*Q. alba*), black cherry (*Prunus serotina*), yellow birch (*Betula allegheniensis*), white ash (*Fraxinus americana*), and white pine generally occur in the upper canopy, with red maple (*Acer rubrum*), and black birch (*Betula lenta*) in the midstory, and beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and hemlock in the lower canopy (Oliver 1978, Kelty 1986, Marquis 1992, Stephens and Ward 1992). If stands are composed of only the shade-tolerant species, they tend to lack stratified structure; it is the difference among the groups of species in height growth rates and ability to survive in shade that creates the structure in even-aged stands.

Many stands across the southern New England region are currently entering a valuable commercial stage, having originated from heavy cuttings that occurred early in the twentieth century. These are either even-aged where the cuttings were complete, or two-aged where residuals had been left during the harvest of the previous stand. Even-aged methods, particularly shelterwood, appear to be the most logical to recreate the composition and structure of these mature stands, and they have been used successfully throughout the region (Hannah 1988, Seymour 1995). However, the timber value of these stands is generally contained in only a small number of trees of select species, with red oak, white pine, white ash, black cherry, yellow birch, and sugar maple among the most valuable. Markets for the other species are either lacking, or where markets exist, their value is so much lower that the opportunity to remove these species to meet silvicultural goals has been largely ignored. High-grading has become a prevalent harvesting strategy, often consisting of removing all well-formed stems of valuable species greater than about 14 in. in diameter at breast height (dbh).

The problem of exploitative harvesting (diameter-limit cutting or high-grading) in eastern forests has been described by Nyland (1992) and quantified in a study in West Virginia (Fajvan et al. 1998). In the West Virginia study, a majority of timber harvests occurring on a cross-section of ownerships were found to be diameter-limit cuts with insufficient residual stocking to allow for a second commercial harvest in the current rotation. Similar effects of the liquidation of valuable overstory species in partial cuttings is evident in regional forest inventories in New England, as low value, shade-tolerant species such as red maple, black birch, hemlock, and beech are retained and thus increase in relative abundance. For example, in Massachusetts, the proportion of total sawtimber volume comprised of these four species rose from 18% in 1972 to 28% in 1998 (Dickinson and McAfee 1988, Alerich 2000). (These generalizations do not discount the fact that some forest properties in the region are managed by methods that avoid these problems associated with high-grading.)

Choice of Selection Method

The appropriate size of canopy opening needed to establish desired regeneration is the issue that appropriately receives most of the attention in planning selection cutting; the question of which trees to cut within the opening is also important, but is stressed less. Because shading from the adjacent mature trees is a major factor that affects regeneration, one important consideration of harvest gap size is the distance that this edge effect extends into the gap (Bradshaw 1992). For this reason, the diameter of a harvest gap is often expressed in terms of the height of surrounding trees. The following relation of gap diameter to area is useful for reference, assuming a tree height of 80 ft and circular openings: 1 tree height = 0.1 ac; 2 tree heights = 0.5 ac; 3 tree heights = 1.0 ac.

Any size of harvest opening can be made by cutting only the overstory trees, or by cutting both overstory and lower canopy trees. This distinction is included in the three terms used to describe regeneration methods in uneven-aged management: single-tree selection, group selection, and patch selection (Leak and Filip 1975). In single-tree and group selection, only overstory trees are cut to create regeneration openings, with the choice between the two depending on whether mature trees tend to occur singly or in groups (Figure 1). It is understood in the general concept of these methods that smaller trees are cut throughout the stand to release young desirable trees from competition, but the smaller trees to be cut are not necessarily within the openings made by the harvest of mature trees. Patch selection differs in that it adapts

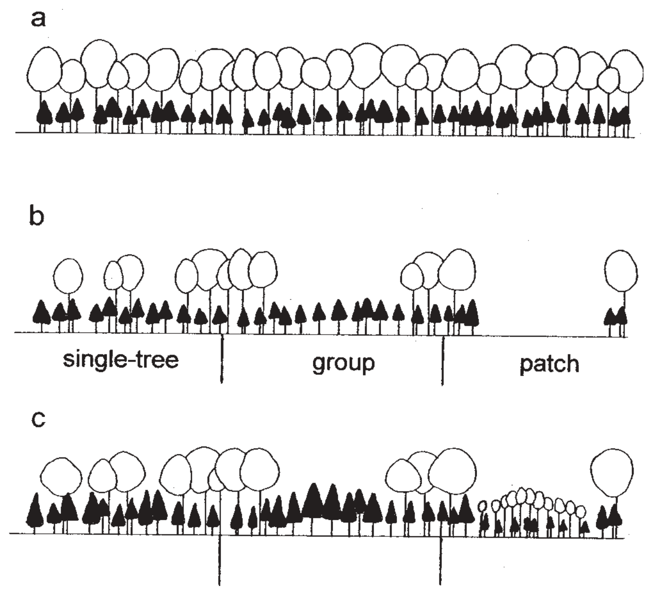

Figure 1. (a) Structure of even-aged, stratified stand with upper canopy of intolerant or midtolerant species and lower canopy of shade-tolerant species. (b) Three approaches to beginning the conversion to uneven-aged structure: single-tree, group, and patch selection. (c) Stand response to cutting, ~20 yr later. Single-tree and group cuts are dominated by shade-tolerant residuals and regeneration; in patch cuts, mixed-species regeneration forms a new stratified canopy.

the patch clearcutting method to the uneven-aged system. The range of sizes for patch cuts can be the same as the range for group cuts, but the key differences are that patch size is predetermined rather than depending on the size of groups of mature trees, and that all trees down to a small diameter (usually 1 or 2 in. dbh) are cut within the opening. Some aspects of the definition of the patch-selection method differ among silviculturists, but this central idea will be used as the defining characteristic here. In even-aged stands that have been previously thinned, there may be little difference between group and patch selection cuts in practice, because midstory trees will have been removed in the earlier thinning. But in unmanaged or lightly managed stands, especially those with stratified canopies, the presence of lower canopy trees in cutting areas creates an important problem.

Single-Tree Selection

Results of studies in eastern forests have shown that the use of single-tree selection will result in a gradual conversion of mixed-species stands to dominance by the shade-tolerant species. In the northern hardwoods type, Leak (1998) studied the 35 yr response to single-tree selection cutting applied to seven stands that were dominated by beech, sugar maple, and yellow birch, with smaller proportions of white ash, paper birch, and hemlock. The three principal species maintained their dominance, whereas paper birch and white ash declined, and hemlock increased sharply. In a study in Appalachian hardwoods (Smith and Miller 1987), single-tree selection was applied with a 10 yr cutting cycle for four cuts (with some variation in timing among plots) in stands comprised mainly of yellow-poplar (*Liriodendron tulipifera*), hickory (*Carya* sp.), and sugar maple. This system resulted in the seedling, sapling, and pole size classes becoming dominated by sugar maple. For these reasons, single-tree selection is generally recommended only where shade-tolerant species are acceptable as the future stand (Nyland 1998).

A kind of partial cutting that has some similarity to single-tree selection is sometimes used in even-aged stands, mainly where most attention is on management of the overstory trees, with less concern for regeneration. This is done as an alternative to high-grading and is often described as selection-cutting, although target diameter distributions are not used because the necessary inventory and marking guidelines are considered too time-consuming (Miller and Smith 1993, personal observation). In this approach, only a portion of the high-value species in the main canopy is harvested, while trees of those species that have not yet reached the target final diameter are retained. Some stems of low-value species are also removed to free growing space for high-value trees. The level of cutting is guided by a target residual basal area. Miller and Smith (1993) presented guidelines for using this approach, which they refer to as flexible diameter-limit cutting combined with improvement cutting. The minimum diameter limit for cutting mature trees is determined by a financial analysis of stumpage prices, which recognizes the drop in the rate of return of trees as they grow past the minimum diameter for high-grade sawlogs. Only on very productive sites can large trees grow fast enough to still earn a high rate of return once they have attained a high present value; thus the diameter limit varies by species value and site quality.

This kind of cutting avoids one short-term negative effect of high-grading by assuring at least a second valuable harvest when the residual overstory trees have reached the sawtimber diameter objective. But it has the same long-term effect on regeneration as single-tree selection, in that it reduces tree species diversity to the few shade tolerant species in the stand (Miller and Smith 1993). This method is probably best considered as a form of thinning, which should be replaced by a regeneration method at some point. Otherwise, the stock of valuable trees will likely be depleted after two such cuttings, with no attention being paid to the establishment of regeneration of desired species. The same conversion of the stand to low-value species will often result, similar to the long-term effect of high-grading.

Group Selection

A number of research projects have studied the application of a method referred to as group selection, but which actually consists of patch selection as defined here; results of those projects will be discussed in the following section. However, one early study in southern Connecticut (Merrill and Hawley 1924), did document the response to a series of group-selection cuttings that were made in an even-aged hardwood-hemlock stand, with oaks as the dominant hardwood species. Only the overstory trees (almost entirely hardwoods) were removed in these cuts, resulting in the release of the existing hemlock understory. This eventually created a nearly pure hemlock stand with an even-aged but uneven-sized structure (with tree size depending on time since the group release had occurred in each part of the stand). Thus the long-term effects of group selection in this stand did not differ substantially from what single-tree selection would have produced.

Patch Selection

A number of studies of patch cutting have directly examined the effect of opening size on species composition and growth of regeneration. The largest of these was conducted on five USDA Forest Service experimental forests in the central hardwood type, in West Virginia, southern Ohio, Kentucky, and southern Illinois (Dale et al. 1995). Although the species composition of these forests differs considerably from that of New England stands, the principles of the effects of patch size on groups of species categorized by shade tolerance are applicable. Sizes of patches ranged from 0.04 to 1.6 ac, and all trees in the patches were cut to a minimum dbh of 3 to 5 in., with smaller vegetation either cut or treated with herbicide (with specific method varying among sites). Regeneration was assessed 30 yr later on sample plots located at varying distances from the edge to the center of the patch. Results showed that the greatest shift in species composition occurred between patch sizes of 0.1 ac and 0.3 ac. Shade-tolerant species dominated the plots close to the patch edge (less that 20 ft), and this edge effect accounted for nearly the entire area of patches up to 0.1 ac. Plots in the center of 0.3 ac patches developed equal stem densities of intolerant and tolerant species. In larger patches, edge plots were still dominated by tolerant species, and the ratio of intolerant to midtolerant to tolerant species remained constant across plots at varying distances farther into the center. However, height and diameter growth of trees (particularly of less tolerant species) in the patch centers did continue to increase with increasing patch size to the largest patches in the study. Thus, the young stands were developing stratified structure at age 30 in the more open parts of the patches.

The effects of patch size on regeneration composition in northern hardwoods were summarized by Lamson and Leak (2000). The trends matched the results described above, with patches less than 0.1 ac being dominated by tolerant species (sugar maple and beech), those from 0.2 to 0.5 ac having 25% of total stem density comprised of yellow birch, paper birch, and white ash, and those from 0.7 to 1.0 ac with 40–50% of the less tolerant species. Smith (1981) found similar results in Appalachian hardwoods in West Virginia. On moist sites, patch cuts of 0.1 ac and smaller were dominated by sugar maple, 0.2-ac cuts had small amounts of yellow-poplar mixed with sugar maple, and 0.4 ac cuts were dominated by yellow-poplar, black cherry, and black birch. The shift in species composition was less distinct on drier sites; beech, red maple, sassafras *(Sassafras albidum)* and oaks dominated in smaller cuts, whereas red maple, oaks, and black birch were most common in larger patches. On both site types, tree species diversity increased with larger patch cuts–shade-tolerant species occurred in all sizes, but with an increasing representation of less tolerant species with increasing patch size.

One study in northern hardwoods (Leak 1999) examined the long-term use of patch selection. Four patch-selection cuttings were made in a stand from 1937 to 1994, with patch size ranging from 0.1 to 2.2 ac (a mean of 0.5 ac in early cuts, increasing to 0.9 in more recent cuts); all trees 2 in. dbh and larger were cut within the patches. A mean of 12% of stand area was cut each time, so the complete stand would be treated after four more cutting cycles, giving a rotation length of about 130 yr. The less-tolerant species yellow birch, paper birch, and white ash had comprised only 10% of original stand basal area, but they had increased to 20% in the diameter classes affected by the cutting, measured 4 yr after the fourth cutting cycle. This would be expected to increase further with future cuttings, as more of the stand was regenerated to a high proportion of those species.

Results of a previously unpublished study of patch cutting in a southern New England stand can be used to gain insight into how the trends identified in these studies in other regions apply to conditions in the transition hardwoods type. The study was carried out on Cadwell Memorial Forest of the University of Massachusetts, with the objective of comparing regeneration in patch cuts and shelterwood cuts. The stand was an even-aged, 75-yr-old stand at the beginning of the study in 1988. The principal species were red oak, white pine, red maple, black birch, and mountain-laurel (*Kalmia latifolia*). Eight 1-ac plots were established; in four plots a uniform shelterwood cutting was made in which the overstory was reduced to a basal area of 60 ft^2/ac, and in four a single circular patch cut of 0.3 ac was cut. To examine the importance of removing the lowest canopy stratum, the understory (all trees and shrubs less than 6 in. dbh) was cut in two plots and retained in the other two plots in each cutting type. Regeneration was measured before harvest in 1988 and again in 1997.

Some seedlings were already present as advance regeneration before the 1988 cutting treatments, but substantial numbers became established after cutting, particularly in the shelterwood plots but also to lesser extent in the patch cuts (Table 1). Ten years after cutting, species composition of regeneration was similar in all plots. Red oak and red maple were the most abundant, comprising greater than 70% of stems in all plots. A small number of paper birch and grey birch occurred in the patch cuts, but were absent from the shelterwood cuts. White oak, black birch, white pine, and chestnut (*Castanea dentata*) were present at lower densities throughout the plots.

The greatest stem density of all species combined was found in the shelterwood plots in which the understory had been removed, and these plots also had the greatest oak stem density (Table 1). Patch cuts had lower total seedling densities with a lower proportion of oak, regardless of understory treatment. However, considering only regeneration greater than 5 ft in height, the patch cuts had greater seedling densities of oak and of all species combined, compared to shelterwood plots; this pattern was more pronounced in the patch cuts with understory removed.

These results confirm those of the more extensive studies described above, which have shown that 0.3-ac patches are large enough to allow species of low and intermediate shade tolerance to become established. They also indicate the importance of removing small trees and shrubs for obtaining high seedling densities that can develop rapidly in height. The effect of competition from sapling and lower canopy trees in particular on growth reduction of red and white oak seedlings has previously been shown for sites in Wisconsin (Lorimer et al. 1994). The comparison between patch cuts and shelterwood cuts also suggests an effect that may be important for management of private nonindustrial lands. Shelterwood stands developed dense regeneration but would require an overstory removal cut to maintain the height growth of regeneration, ideally occurring less that 10 yr after the establishment cut, judging from the slow height development in these plots. Patch cuts are not dependent on a timely second cutting, which is an important consideration with the low intensity of management applied to many of these properties.

Regulation of Cutting at Stand Level

Ideas concerning the regulation of cutting levels during selection-system harvesting have been based on methods first developed for creating a sustained-yield forest composed of even-aged stands. The simplest method at the forest level is to use area control to develop a balanced forest—that is, to create equal areas of stands of each age class. However, differences in growth rates among stands usually occurs because of variation in site quality and species composition across a large forest. This usually makes it necessary to use some form of volume control to modify the simple allocation of stand area. Uneven-aged stands can be managed, at least

Table 1. Densities (stems/ac) of oak species and of all species combined in demonstration plots on Cadwell Memorial Forest just before treatment (1988) and 9 yr later (1997). Treatments are a combination of overstory cutting method and understory removal or retention. Each value is the mean of two 1 ac plots.

	Understory	0–5 ft		>5 ft		All heights	
Cutting method	treatment	1988	1997	1988	1997	1988	1997
All species combined							
Group	Retained	4,700	5,700	700	2,940	5,400	8,640
Group	Removed	4,820	3,120	620	4,450	5,440	7,570
Shelterwood	Retained	2,980	6,725	660	550	3,640	7,275
Shelterwood	Removed	2,720	13,490	880	1,290	3,600	14,780
Oak species only							
Group	Retained	1,250	2,020	0	180	1,250	2,200
Group	Removed	1,140	1,210	0	630	1,140	1,840
Shelterwood	Retained	590	3,530	0	40	590	3,570
Shelterwood	Removed	1,180	9,440	0	40	1,180	9,480

conceptually, as a sustained-yield forest on a small scale, referred to as a balanced uneven-aged stand. Because site quality and species composition generally has less variation within a single stand than across a forest, the idea of area control should apply better to an uneven-aged stand than to a large forest. However, when the harvest of mature trees is restricted to single trees or small groups or patches, it is impractical to measure and keep track of the area harvested. Therefore, the use of target diameter distributions as a form of volume control of cutting has been favored.

The problem with the use of diameter distributions has been with the lack of a method to choose the appropriate one. Yield tables for even-aged stands of the forest type in question cannot be used because young trees growing in partial shade in selection stands do not develop at the same rates as those in the open in even-aged stands. Early researchers found that old uneven-aged stands had diameter distributions that followed a simple mathematical equation, in which the numbers of trees in each diameter class (usually 2 in. classes) are a multiple of the number in the next larger class; the multiplier is a constant for all diameter classes in a stand, and is called the "*q*-value" (Smith et al. 1997, Nyland 2002). This form of equation produces the characteristic negative exponential or reverse-J-shaped curve associated with balanced uneven-aged stands. The basic idea of this method is to cut the stand to the target distribution; the stand then is expected to grow back, maintaining the same distribution shape but with greater number of trees throughout, and the process is then repeated with the next cutting. Although *q*-values have been the focus of much of the discussion of the control of cutting in the selection method, Nyland (2002) noted that there are no methods to decide on which *q*-value to use for different stands or objectives, nor has research provided evidence that stand structure will remain stable over time with use of a *q*-value distribution as a cutting guide. In fact, studies have shown that stands cut to a *q*-value distribution do not maintain this structure, and tend to diverge from it in predictable ways (Leak 1998). As an alternative, diameter distributions have been defined by using two or more *q*-values (different values for different ranges of the distribution); by using results from long-term trials (Nyland 2002); or by using ecological models based on relationships between leaf area and stem growth (O'Hara 1998).

However the target diameter distribution is calculated, the problem of the time involved with the detailed inventory and marking guides still exists. Methods have been developed to convert marking guides from 2 in. diameter classes into three to five broad diameter classes to use as a marking guide (Leak and Gottsacker 1985, Nyland 2002). Even with this simplification, the method becomes difficult when using group or patch selection—it is necessary to combine diameter-class marking guides with a tally of the area in groups. Experience has shown that this combined method becomes difficult with groups or patches larger than 0.1 ac (Leak and Gottsacker 1985). Because the cutting level in the patches is clearly heavier than indicated by the marking guide, the rest of the stand would have to be cut more lightly than the guide in order for the stand to meet the target distribution overall; thus, no part of the stand would be cut to the target structure.

With large patches of the size needed for regeneration of less tolerant species, it may be more logical to return to the original concept of relying entirely on area control (Leak 1999). For a given stand area, cutting cycle, rotation age, and average patch area, it is possible to calculate the number of patches to be cut and to use patch diameter to lay out the cutting areas. The stand area between the patches can be thinned during the same stand entry. Since this nonpatch part of the stand is not being regenerated during this entry, even-aged thinning or improvement cutting methods are appropriate.

Finally, the use of any diameter distribution method does not appear to be helpful in the first step in conversion of an even-aged stand. The assumption of all diameter-distribution methods is that tree diameter is correlated to tree age, and the objective is to maintain appropriate numbers of young trees to develop rapidly into the large size classes. However, in an even-aged stand, the smaller trees are not younger trees and are often of different species than the largest overstory trees. Thus, a target reverse-J-shaped distribution may confuse more than clarify the selection of which trees to cut. The first step in the conversion process is to obtain regeneration in parts of the stand; after one or two cutting cycles in which patches of regeneration are created, the use of diameter distribution guides may be helpful because younger trees will be present in the stand at that time.

Large-Scale Implementation on Public Watershed Lands

The Massachusetts Metropolitan District Commission (MDC) actively manages approximately 100,000 ac of forest on four watersheds, which provides drinking water for 2.4 million people in Massachusetts, primarily in metropolitan Boston. The primary objective of management is the protection of drinking water, but the forest management program also provides timber revenues approaching $1,000,000 annually. MDC forest managers have committed to an uneven-aged approach to management that seeks to maintain a multilayered forest cover of high tree species diversity that is resistant and resilient in the face of disturbances ranging from localized damage from insect, disease, and ice storms to catastrophic windthrow from hurricanes (Barten et al. 2000).

The largest block of MDC watershed land is the 58,000 ac forest surrounding the Quabbin Reservoir in western Massachusetts. It is comprised mostly of even-aged stands, originating as natural regeneration following heavy cuttings, catastrophic hurricane damage, or abandonment of agriculture, or as plantations established on open fields. Past management in maturing stands had consisted mostly of thinnings and improvement cuttings because heavy browsing by the large deer herd had eliminated the possibility of regeneration using any silvicultural method. A change in regulations in 1990 allowed the reduction of the deer herd through controlled hunting, and the problem of forest age-structure conversion could then be addressed.

A limitation in the intensity of management (imposed by the limited size of the forest management staff) means that the cutting cycle cannot be less than about 30 yr. The objective chosen was to create three age classes in each stand, rather than four to six, as is generally associated with the selection system. Thus, about one-third of each stand is to be cut every 30 yr, with the creation of dense regeneration being the key goal. This major shift in silviculture necessitated experimentation. The initial approach was a mixture of single-tree selection and group selection, using a target diameter distribution based on a *q*-value of 1.8 and a maximum diameter of 22 in. However, in applying this method to even-aged stands, it was found that harvesting approximated a diameter-limit or high-grading cut, because the surplus in the diameter distribution was all in large-diameter trees, and the deficiencies were all in small trees (Figure 2). Thus, in many stands, overstory oak and pine would be recommended for partial removal by the use of this method, and overtopped red maple and black birch would be reserved as the future stand. This would occur with a range of *q*-values, even though many even-aged stands tend toward a reverse-J-shaped curve because of the differentiation among species in diameter growth (Figure 2).

The marking guidelines were soon shifted to the use of patches in which both merchantable overstory and unmerchantable smaller trees are cut, except for advance regeneration of desired species. Minimum patch size is 0.5 ac, which is sufficient for regeneration to grow freely for the required 30 yr period. In the current method, cutting is controlled by the proportion of the stand to be in openings (usually one-third of the stand), and the desired size of opening (generally 0.5 to 1.0 ac, with size and shape determined by topography, stand structure, and hydrologic factors). Areas between the patch cuts are thinned, with basal area used as a guide to determine the intensity of the cut. The total harvest (patch cuts and thinnings) amounts to about 50% of total stand basal area.

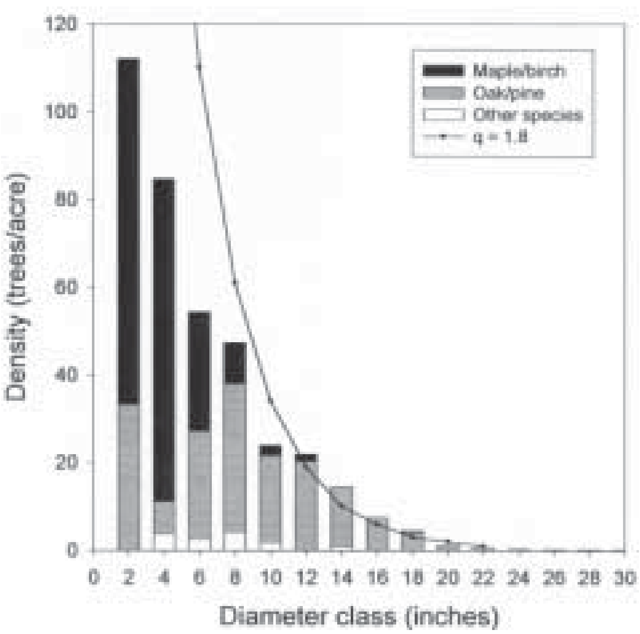

Figure 2. Application of target diameter distribution with *q*-value of 1.8 (line) to existing structure of an even-aged stand (bars) on Quabbin watershed forest. Stand is composed principally of red, black, and white oak, white pine, red maple, and black birch. This approach recommends cutting only trees ≥ 12 in. dbh, mainly oak and pine.

An analysis of the total cut using a *q*-value of 1.8 has been conducted to compare pre- and post-cut diameter distributions, but it is not clear that this analysis is proving to be helpful. Its use is in question for a number of reasons. First, the overall objective of management does not require consistent yields of timber from any one stand, which is the goal of the diameter distribution method. Also, the management objectives do not define a maximum diameter to guide the choice of a specific target diameter distribution. After the first two cycles of cutting in a stand (i.e., after 60 yr), portions of the oldest residual will be allowed to grow to biological maturity for habitat conservation goals. The timing and spatial pattern of the third cutting will be adjusted based on the vigor of the oldest age class, by methods yet to be determined. Thus, the form of the selection method currently used on the Quabbin watershed forest has been developed because it will accomplish the objectives of maintaining an uneven-aged forest structure with high tree species diversity for watershed protection. It will serve to focus attention on establishing dense regeneration and creating a patchy stand structure rather than on meeting a predefined mathematical goal for the diameter distribution.

Conclusion

Research results and management experience from northern hardwoods, central Appalachian hardwoods, and transition hardwoods are in agreement on a number of silvicultural aspects associated with converting even-aged stands to uneven-aged structure:

1. Canopy openings should be 0.3 ac or larger if the goal is to promote regeneration of intolerant and mid-tolerant species in addition to shade-tolerant species.

2. These openings should be made as patch cuts rather than group cuts. The important aspect is that midstory and understory trees should be cut within the openings, while any desired advance regeneration present in the openings is retained. The objective of releasing established advance regeneration can often be an important factor in determining the placement of the patch cuts.

3. Diameter-distribution guides have not proven useful for determining cutting levels when using large patch cuts, especially in the first cut in an even-aged stand, when diameter does not relate to the age or potential of trees to respond to release. Controlling the cut by allocating the proportion of stand area to be in patches is more straightforward and more likely to create the desired stand structure.

The stress on the patch-selection system in this article should not be understood as an indication that it is the only approach to create diversity in structure and species composition in stands that are currently even-aged. As an alternative, the entire stand could be converted to a two-age structure using clearcut-with-reserves or shelterwood-with-reserves, with the older age class retained as individuals or irregularly spaced groups (Miller and Kochenderfer 1998). Also, these ideas could be incorporated into the patch-selection system, with each patch treated as a small-scale shelterwood or a clearcut-with-reserves. This may be especially useful with larger patch sizes.

One advantage of using patch cutting as the first step in the regeneration process is that it leaves options for the next treatment 20 to 30 yr in the future. Patch cutting could continue in order to create an uneven-aged stand, or the patches could be incorporated into a group shelterwood method by enlarging the patches and applying a shelterwood establishment cut to the rest of the stand. Maintaining options is a valuable aspect of patch cutting that contrasts sharply with high-grading and diameter-limit cutting, which reduce future options with each successive cut.

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