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Professional Hardwood Notes
Technical Information on Hardwood Silviculture for Foresters

Uneven-age Management in Mixed Species, Southern Hardwoods: Is it Feasible and Sustainable?

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According to The Dictionary of Forestry (Society of American Foresters 1998), the definition of an uneven-age stand is "a stand with trees of three or more distinct age classes …"; the uneven-age silvicultural system is "a planned sequence of treatments designed to maintain and regenerate a stand with three or more age classes." For uneven-age stands to develop, both young and old trees need to be developing in the same stand, where younger trees are naturally smaller in diameter than older trees. Thus, guidelines and graphs used by foresters to help establish uneven-age stands use diameter as a surrogate for age and assume that age and diameter are related (Figure 1). Typically, diameter distributions of uneven-age stands form a reverse J-shaped or negative exponential curve, where the number of small trees per acre is greater than the number of large trees. The curve can create the assumption that tree age and tree size are congruent.

Too often small trees are equated with young trees. Although young trees are usually smaller, it is not always true that small trees are younger. Different species grow at different rates, separating into various size and crown classes. The most rapidly growing species over the long run dominate the upper canopy,

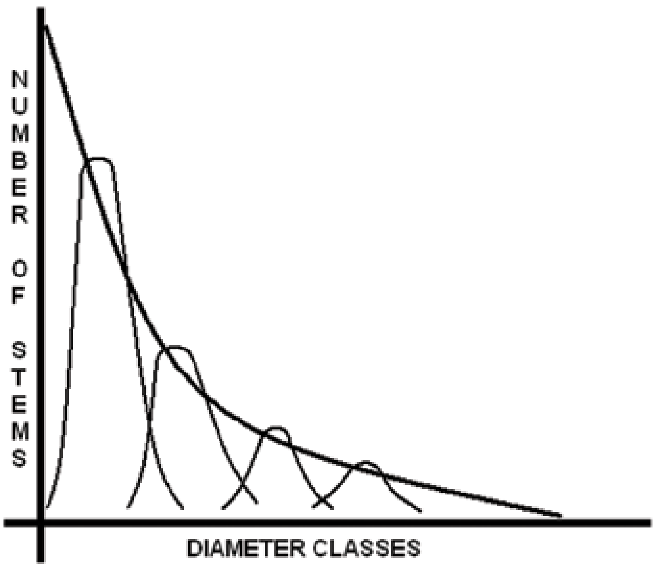

Figure 1. A graph illustrating the diameter distribution of a balanced, uneven-age stand. The bell-shaped curve for each diameter class represents the diameter distribution for that particular size class. Plotting the midpoints of each diameter class results in a reverse J-shaped or negative exponential function.

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Shade-tolerant, midstory species (dogwood, blackgum and sourwood) are perpetuated with single-tree selection.

relegating the slower-growing species to the mid-canopy and understory. What appear to be young, small trees ready to occupy the upper canopy when the harvest of the upper canopy trees is completed are usually a stratified mixture of species of a similar age. It is not unusual to find trees in the midstory and understory that are similar in age as the trees in the upper canopy. Instead of being young, vigorous understory trees waiting for an opportunity to grow, these trees are often older, small-diameter trees with little growth potential. Many even-age or two-age stands may have a similar diameter distribution as uneven-age stands, but the differential in diameter is not related to age. Serious forest management mistakes can be made in implementing the uneven-age system when it is assumed that small trees are younger than the larger trees (Clatterbuck 2004).

Many property owners prefer the uneven-age silviculture system because of its visual attractiveness. Attributes include: a continual canopy is maintained, large-diameter trees are always present and size classes are interspersed, providing habitats for many plants and animals. Several biological, economic and management obstacles must be overcome for the uneven-age system to be feasible, successful and sustainable in southern hardwoods. Other management approaches can also simulate many of the visual attributes associated with the uneven-age system.

The uneven-age system is perpetuated by the selection method of regeneration, either single-tree where scattered individual trees are removed or group selection where removal occurs in groups distributed across the stand (typically less than 1/2 acre in size). The forest canopy remains largely intact. The structure of an uneven-age stand is multiple canopy layers represented by different size classes. Usually when a tree is removed, nearby trees respond by growing larger and into the space vacated by the removed tree. The goal is for smaller size classes of trees to grow progressively to larger sizes as trees are removed. Reproduction is established during each cutting cycle to successfully regenerate new trees.

A number of biological tenets and operational concerns must be addressed to maintain uneven-age forests using selection methods. These tenets and concerns should be understood to determine if the uneven-age system is appropriate, and if so, which selection method can best be implemented to provide the desired results. Some of these biological tenets and operational concerns including those outlined by Guldin et al. (1991) are:

- Single-tree selection provides for the regeneration of shade-tolerant species and is best suited for the management of these species. Single-tree selection can be problematic if shade-intolerant species are preferred.
- Requirement to create conditions that promote regeneration with each entry or cutting.
- Trees must be able to progress from one size class to another, thus providing a relationship between diameter and age.
- A requirement for frequent entries and cutting of trees through the entire stand and the need to avoid wounding residual trees from repeated entries.
- Cutting must occur in all size classes, even down to the small pre-commercial sizes (2 to 8 inches).
- Cutting should avoid removing only the highly valued trees in large, commercially viable size classes (high-grading).
- Long time periods to allow for the development of at least three age classes require continuity of management.
- Marking of trees for harvesting must be highly controlled.

This publication provides information on the biological and operational tenets associated with sustaining uneven-age forests to those interested in exploring uneven-age management in southern hardwood stands.

The Uneven-age System

Effects on Species Composition

Significant portions of the canopy remain intact with the selection regeneration methods. Therefore, shading on the regenerating age class is an important consideration. Only shade-tolerant trees can successfully regenerate and grow at low light levels encountered with single-tree selection. Shading effects can also be pronounced with group selection when the group is relatively small. The selection methods are best-suited for shade-tolerant species that have the ability to regenerate and prosper in the shade. When applied to stands of intolerant species, composition will shift to more tolerant species that occur in the shade beneath the upper canopy. Table 1 provides a listing of tree species common to southern hardwood forests by shade tolerance. This table can be used to determine those species that can be successfully developed using single-tree selection. Unfortunately, the majority of the commercially valuable species is classified as intermediate or shade-intolerant. If management has timber as one of

Photo Credit: Wayne K. Clatterbuck

Logging damage on residual trees is common when harvesting at frequent intervals.

Table 1. Shade tolerance of common species in southern hardwood forests.

Shade Tolerance Classification		
Intolerant	Intermediate	Tolerant
Black cherry	American elm	American beech
Black locust	Green & white ash	American holly
Black walnut	Hackberry	American hornbeam
Black willow	Hickories[a]	American holly
Eastern cottonwood	Oaks[b]	Blackgum
River birch	Yellow birch	Boxelder
Sassafras		Buckeye
Sweetgum		Eastern redbud
Sycamore		Eastern hophornbeam
Yellow-poplar		Flowering dogwood
		Persimmon
		Red & sugar maple
		Sourwood

[a] Hickories as a genus are mostly intermediate in shade tolerance. Mockernut and bitternut range more toward the intolerant scale.
[b] Oaks as a genus are mostly intermediate in shade tolerance. The red oak family ranges more toward the intolerant scale.

Source: Burns, TM; Honkala, B.H. 1990. Silvics of North America. Agric. Handb, 654 (2 volumes). Washington, DC. USDA Forest Service the objectives, the use of single-tree selection could easily decrease the ability to grow and capitalize on timber value.

In uneven-age stands, stand structure depends on the growth of various size classes within that structure. Growing stock is controlled through determining the residual stocking level to be left after harvesting, the diameter of the largest tree, and the number of trees desired in each diameter class.

Stocking goals, usually expressed by volume or basal area, are usually set such that growth is concentrated on the fewest larger trees without losing growth through understocking. This minimizes the time taken to grow trees to a given diameter. The maximum diameter of trees left to continue to grow after harvesting usually depends on management objectives. Frequently, the diameter when growth begins to occur at a decreasing rate (financial maturity) sets the maximum diameter. Depending on site productivity, most hardwoods with diameters of 24 inches and above are normally not growing at an acceptable rate.

To control the number of trees in each diameter class requires an expression of defining the reverse J-shaped curve of uneven-age stands. The position of the curve on the horizontal axis (x-axis) is fixed by the choice of the tree of largest diameter, the residual stocking level determines the position of the curve between the x- and y-axis, and the slope of the curve is the desired distribution of diameter classes. This slope is defined by the diminution quotient (q) which expresses the ratio of the number of trees in any diameter class to the number of trees in the next higher diameter class. Usually q ranges from 1.3 to 2.0 for 2-inch diameter classes. Low values of q result in a flat curve, which produces a stand with a higher proportion of growing space devoted to larger trees. Stands managed with higher values of q have more trees in the smaller size classes. Thus, depending on the value of q and the maximum diameter desired, stocking and stand structure can be manipulated to meet management objectives. Stand attributes of different q-values are compared in Table 2.

A hypothetical example of calculating number of trees per acre and basal area for each 2-inch diameter class with a maximum diameter of 24 inches for two different q-values is given below. Assume the following:

Example A.

Two trees per acre of maximum diameter of 24 inches and a q of 1.3

Example B.

0.5 trees per acre of a maximum diameter of 24 inches and a q of 1.8

In example A, more growing space is allocated to trees of larger diameters. Basal area is at 71 ft^2 per acre which is below full stocking. Generally, stocking in uneven-age stands is maintained below full stocking to allow space for further growth and the progression of trees to larger size classes.

In example B, most of the basal area is in the smaller size classes and the basal area of 114 ft^2 per acre is at or above full stocking. With this diameter distribution, space is not available for further growth. Cutting is required to allow more growing space so trees remain vigorous and will progress to larger sizes.

Table 2. Comparison of stand attributes with varying q-values.

	***q* = 1.2**	***q* = 1.5**	***q* = 1.8**
Stems per Acre	Low	Medium	High
Size of Stems	More sawtimber Less reproduction	Less sawtimber More reproduction	Least sawtimber More reproduction
Seedling/Mature Tree Ratio	Low	Medium	High
Wildlife Cover	Low	Medium	High
Landowner Goals	More toward timber	Compromise between timber and aesthetics	Least timber

Diameter Class (inches)	Number of Trees per Acre	Basal Area (ft²) per Acre	Number of Trees per Acre	Basal Area (ft²) per Acre
	Example A →	***q = 1.3***	***Example B →***	***q = 1.8***
4	27.6	2.2	178.5	15.5
6	21.2	4.2	99.2	19.4
8	16.3	5.6	55.1	19.2
10	12.5	6.8	30.6	16.7
12	9.6	7.5	17.0	13.3
14	7.4	7.9	9.4	10.0
16	5.7	8.0	5.2	7.2
18	4.4	7.8	2.9	5.1
20	3.4	7.4	1.7	3.5
22	2.6	6.9	0.9	2.4
24	2.0	6.3	0.5	1.6
Total	112	71	401	114

The maximum diameter, the number of trees desired at maximum diameter, or the *q* should be altered to reduce stocking to more desirable levels that will ensure growth to greater size classes.

The creation and maintenance of an uneven-age stand from an even-age stand is a long-term proposition and can be laborious. Often, there is a loss of growth potential. For example, if a 50-year rotation is desired and a 10-year cutting cycle is implemented, one-fifth of the stand is removed during each cutting cycle. If the stand is 50 years, then some trees would be 100 years old before they are harvested. If the stand is younger, then the first cutting would harvest immature trees and the last ones would be overmature. In either case, a financial loss may be incurred (Figure 2).

In addition, the average length of forestland ownership for private owners is 10 to 15 years, a time period that is not conducive to implementing and maintaining uneven-age structure. Usually, several cutting cycles must take place to develop uneven-age structure (at least three age classes). The

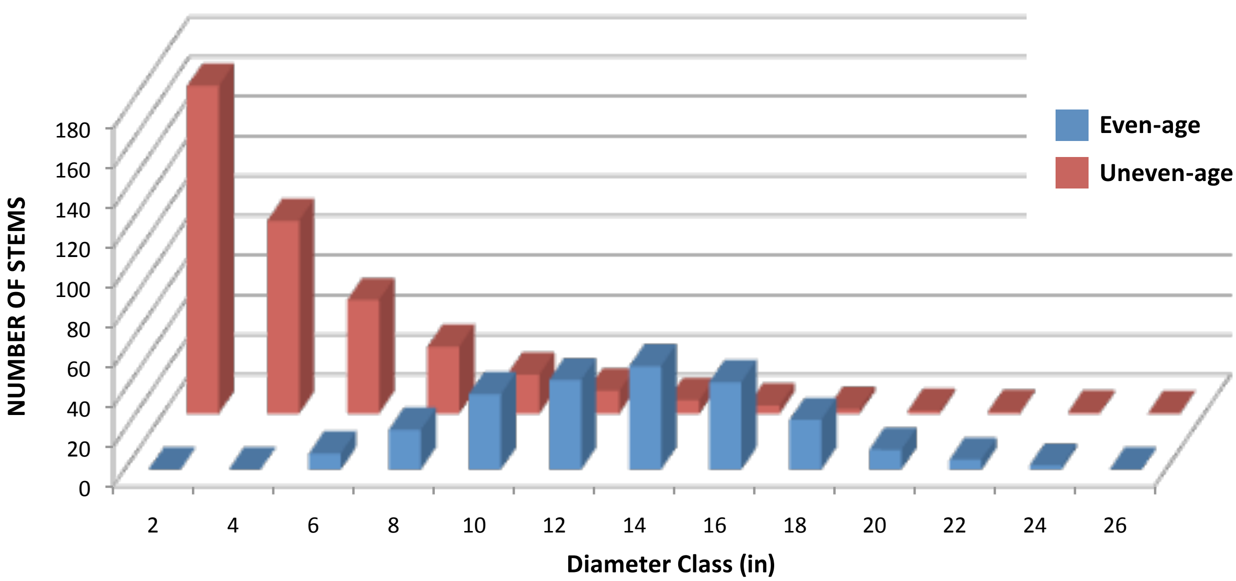


Figure 2. Diameter distributions of an even-age stand and a uneven-age stand representing how the distribution should be manipulated to change a stand with even-age structure to one with uneven-age structure.

long-term, steady ownership of public lands may be more appropriate for the uneven-age system.

The previous discussion is based on a balanced size-class distribution based on the reverse J-shaped curve. Balanced, uneven-age stands are a human construct that generally do not occur in nature and *q*-value is an arbitrary diameter distribution to demonstrate how stocking control can be influenced. Sustainability can be achieved with a variety of stand structures. Thus, silviculturists can design and implement a variety of stand structures that meet a diversity of objectives and allocate growing space to the stand components desired. However, uneven-age stands usually require:

- Maintaining trees of different size classes in the same area
- Frequent periodic harvests that are more or less equal in time (cutting cycle)
- That trees are removed on an individual basis to leave a desired number of trees in each size class
- That each harvest stimulates reproduction and enhances the growth of remaining trees.

Many mixed hardwood stands are even-age, but the diameter distribution curve resembles the uneven-age system. Called even-age stratified mixtures (Figure 3), these stands were initiated at the same time after a disturbance. Several species with different growth rates give these stands an uneven-age appearance, but they are even-age. These stands have stratified canopies, with the fastest-growing, intolerant species as dominants, trees with more intermediate tolerance as codominants and more shade-tolerant species in the midstory. These stratified even-age stands are common on hardwood sites that have higher productivity. Even though even-age, these stratified species mixtures resemble uneven-age structure.

Frequently, irregular uneven-age stands occur due to past disturbances or cutting practices. These stands still have three or more age classes, but the stems are not evenly distributed throughout the diameter classes (Figure 3). The creation of irregular, uneven-age stands can be accomplished much faster when compared to the balanced approach, but potential losses in productivity remain a consideration. Harvesting from all available size classes is necessary to ensure the progression of trees to larger size classes.

Similar to balanced uneven-age stands, in irregular uneven-age stands the larger, financially mature trees are removed, either as individuals or small groups. Some cutting in all diameter classes is necessary so

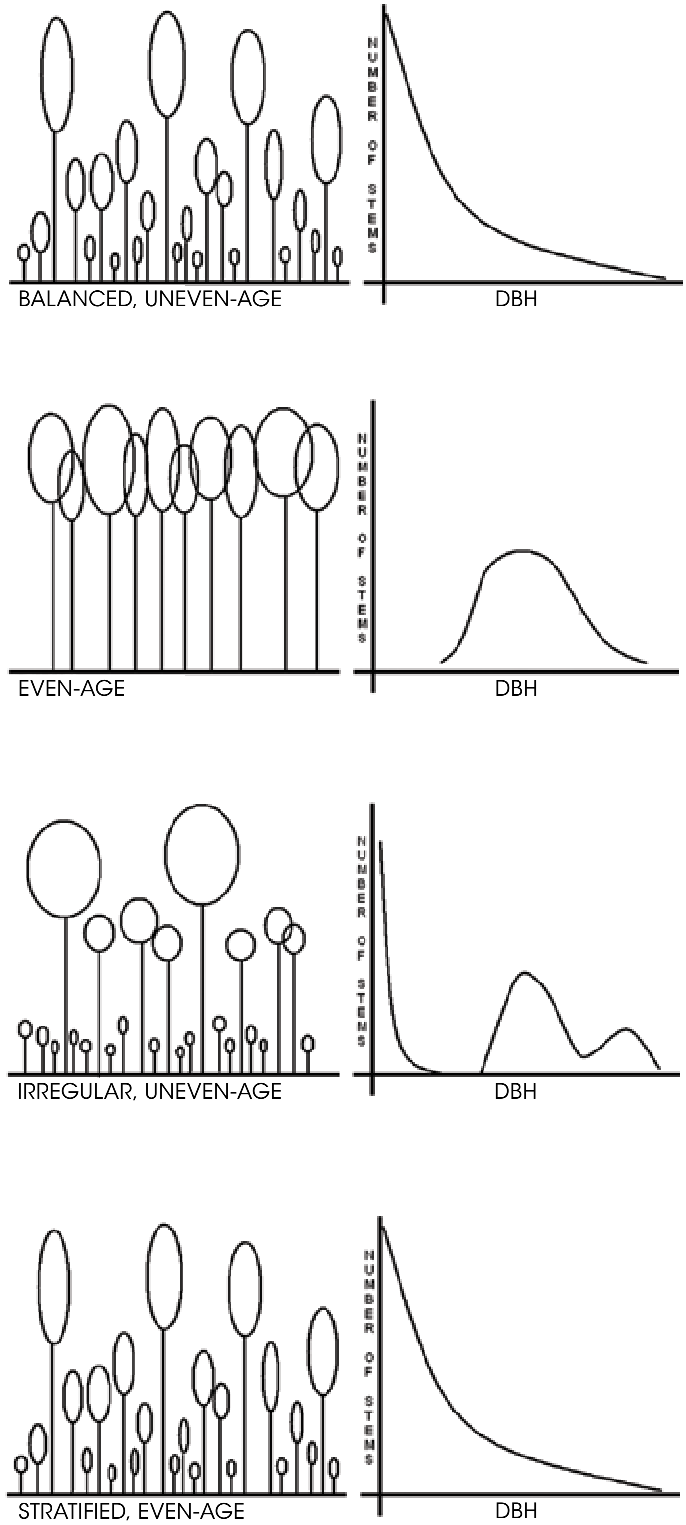


Figure 3. Examples of four stands with their respective stand structures exhibiting the appearance of stands in vertical cross section and corresponding graphs of diameter distributions with number of trees per unit area. The balanced, uneven-age structure resembles stratified, even-age structure even though the number of age classes is different.

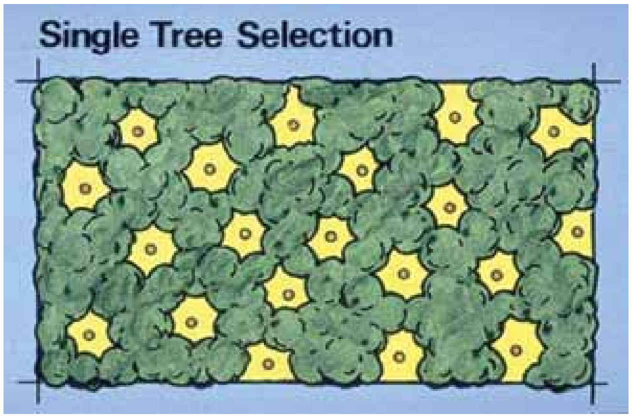
that growing space is created for trees to continue to increase in size. Harvested trees represent the periodic growth between cutting cycles. Maintaining uneven-age structure, however, provides some management flexibility. Trees at or exceeding the maximum diameter may be retained if they are still vigorous and healthy. High-risk trees that are unlikely to survive to the next cutting cycle can be harvested, as well as poorly formed trees. To achieve diameter distribution goals, cutting may occur more heavily or lightly within a size class (Figure 2).

Small trees in the smaller size classes cannot be ignored. These trees represent the trees of the future. Density within size classes should be controlled to foster ingrowth and regeneration. The trees to keep among the immature classes are those of the desired species, best quality, soundness, form, vigor and offering the best probability of survival and growth.

Regeneration Methods for Uneven-age Stands

Single-Tree Selection

Small individual tree openings are created when mature trees are removed. These small openings allow space to regenerate new stems and space for adjacent trees to expand in the once-occupied space. The number of mature trees removed depends on the space allocated to that size class. Immature stems are cut or thinned to balance the size-class distribution by redistributing the growing space among fewer stems while optimizing growth potential. In single-tree selection, these processes occur simultaneously for each cutting cycle: regeneration, expansion of crowns of adjacent trees and reallocation of growing space to balance size-class distribution.



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Single-tree selection is a regeneration method for the uneven-age system.

Photo Credit: Robin Bible

An even-age stratified mixture has a structure that resembles uneven-age stands.

Single-tree selection with small opening size promotes shade-tolerant species such as maples, beech, hemlock, blackgum and many midstory species such as dogwood and sourwood (Table 1). Obstacles to the single-tree selection method include the inability to regenerate more valuable shade-intolerant species, a reluctance to invest in tending immature stems and the unwillingness to conduct inventories to determine diameter distribution. Another consideration is the damage associated with harvesting to the residual stems, particularly for trees in the smaller diameter classes where form can be adversely affected by damage. Other obstacles include the clustering of mature stems, making single-tree selection difficult to implement; the potential degradation of the stand through repeated cutting of the best stems without investing in promoting smaller stems (cutting in all size classes, even the precommercial small stems); and creating conditions for regeneration of desired species.

Single-tree selection is practiced with volume regulation of the harvest where the growth between cutting cycles is removed at each entry. This practice ensures a sustained yield harvest, but a balanced distribution of size classes is essential. Generally, the tail of the diameter distribution curve, i.e., the financially mature trees are harvested (Figure 1), while creating conditions (growing space) for the progression of the remaining trees to larger size classes. Often, the neglect of trees in the smaller size classes and failure to obtain regeneration during each cutting cycle has led to high-grading, leaving inferior trees to perpetuate the stand (refer to high-grading sidebar).

Group Selection

As an alternative to single-tree selection, group selection is the cutting of stems in small groups rather than individuals. Usually the diameter of the area harvested is less than 1.5 to 2 times the average height of the mature trees or less than ½ acre. Small groups are designated for harvest to open the canopy for new regeneration, and groups of immature stems are thinned to maintain size-class distributions.

Group selection is favorable to more intolerant species that do not regenerate in the small openings created by single-tree selection. By modifying the size and arrangement of the group cuts, a wider range of environments is created, providing conditions that are more beneficial for a variety of species. This range of environmental conditions produces greater diversity of habitats for many wildlife species. Reproduction occurs in small, even-age groups in which tracking age class development is easier. However, the group openings are influenced by adjacent trees that can affect growth within the opening.

Dale et al. (1996) documented the effect of opening size on species development and growth for a wide range of openings from 0.1 to 3.0 acres in central Appalachian mixed species stands. In openings less than 0.5 acres, shade-tolerant species dominated. Openings that were 0.5 acres in size allowed the establishment and development of both shade-tolerant and intermediate species (ex. oaks). A significant prevalence of shade-intolerant species in the regenerating age class was established in openings greater than 0.5 acres. The larger openings contain a variety of species with differing shade tolerances. These data indicate that group selection openings with a maximum diameter of 1.5 to 2 times of average overstory tree height (approximately 0.5 acres) may not be adequate to develop shade-intolerant species.

Other considerations are logging costs and regeneration efficiencies of group selection opening size. LeDoux (1999) studied the same openings used by Dale et al. (1985). Although the opening sizes ranged from 0.04 to 1.61 acres, the openings in excess of 0.5 acres were considered as group openings for terms of this study. Generally, total harvesting costs increase as the size of opening decreases. After 30 years of regeneration results, smaller group size had fewer trees per acre, smaller trees and more

Photo Credit: Phil Blakley

Group selection is defined as openings that are less than 1.5 to 2 mature tree lengths in diameter (< 0.5 acre). These patches are 2 to 4 acres in size and are classified as even-age patch openings.

The High Cost of High-Grading

What is high-grading?
High-grading is a timber harvest that removes the trees of commercial value, leaving small trees, as well as large ones of poor quality and of low-value species. High-grading reduces the value of the stand by removing the largest, most valuable trees and increasing the percentage of the poor quality and traditionally low-value species, e.g., red maple, beech, elm.

How does it occur?
High-grading occurs when landowners sell infrequently, are unaware of the consequences of how the trees are removed and have immediate needs for income. High-grading is also common where there are limited markets for smaller and lower quality trees, but good markets for high quality, more valuable trees. Communication is often confused when terms like selective cutting and diameter-limit harvesting are used to imply good management, while removing the best trees and leaving the poorer trees with little potential for improvement. Since trees in most wood lots are the same age, cutting the biggest trees does not leave young ones to grow. Rather, these cuttings take out the fastest-growing trees, leaving slow-growing, less-vigorous trees of the same age as those removed.

What is the difference?
In most cases, high-grading results in a greater harvest volume and value from the first cutting, compared to forests managed silviculturally. However, neither the harvest volume or timber quality is sustained over the long run. After a high-grade harvest, the forest provides:

– Less total volume because of slow-growing trees and irregular spacing between them
– Less volume from large trees of the more valuable size classes (16”+ and veneer)
– More volume from poor-quality trees and low-value species
– Less frequent opportunities to return for another harvest

How do you tell if forest land has been high-graded?
High-grading is highly variable. In some instances, some trees with good favorable attributes and growth potential are left after the cut. In other instances, there is often not much left to work with after all the “good” trees are gone. High-graded woods have:

– Few “good” trees remaining
– More “poor” trees remaining
– Patchy distribution, dense clumps, wide openings

What to do?
With high-graded stands, three options for management are generally available: (1) rehabilitate the stand, (2) regenerate the stand, and (3) postpone action and leave the stand alone. Refer to Clatterbuck (2006) for more information on restoration strategies.

Unfortunately, leaving the stand alone is the option used too often. Rehabilitation of a degraded stand requires a measure of acceptable growing stock (AGS); trees of commercial and desirable species that are capable of increasing in value and volume, and are or can become viable crop trees. If the stand does not have enough AGS to produce a new stand, then regeneration of the stand is necessary. Regenerating the stand often has the potential to create a better-quality stand than what is currently on the site. However, upfront costs of regenerating the stand (site preparation and control of residuals) with little derived income are often excessive and a deterrent for most landowners.

If the stand has been high-graded, AGS should be inventoried. The treatments prescribed will depend on the extent of the high-grading and the AGS available. Stands containing approximately 50 ft^2 basal area of AGS per acre are adequate for future growth (albeit at less than full stocking) and may require some improvement cutting in the future to enhance growth of AGS. Where AGS is 20 to 50 ft^2 basal area per acre, consider some type of regeneration cut in the near future, merchandising or deadening undesirable, larger residual trees and releasing desirable seedlings and sprouts. Although stands are growing at less than capacity, existing AGS is being promoted until their value can be captured. Where AGS is 5 to 20 ft^2 basal area per acre, regenerate the stand. Most of these restoration strategies will incur some costs with little initial return, but are required for rehabilitation to a more productive growing status.

Photo Credit: Chris Oswalt

Japanese stiltgrass, an invasive exotic species, was released following the harvest and will limit regeneration of desired species.

shade-tolerant species. Larger groups had increasingly more trees per acre, larger trees and more shade-intolerant species. A simulation model was used to integrate harvesting technology, silvicultural treatments, market price, growth projections and discounted present net worth economic projections. Financial yields were maximized using openings of 1.25 acres or larger, primarily because of logging efficiency of larger groups and the growth, volume and species composition (higher-valued, more shade-intolerant species) of the larger openings. Most silviculturists do not recognize opening size greater than 0.5 acre as a group opening, but more as a patch opening or clearcut with even-age attributes. Thus, even though group selection openings are larger in size than single-tree selection openings, the financial aspects are still questionable when considering logging efficiencies and regeneration aspects.

The advantages of group selection are that harvests are more concentrated, causing less damage to residual trees; greater flexibility in creating environmental conditions that favor regeneration of more shade-intolerant species; and reproduction develops in more defined, even-age aggregations. However, many of the same obstacles are evident as with single-tree selection, including the unwillingness to tend immature groups as well as difficulties with determining spatial distributions through inventories.

The group selection regeneration method is usually conducted within area regulation of the harvest. With area regulation, sustained yield is not at the stand level, but at the forest level. Thus, group selection does not necessarily produce uneven-age stands, but it does create uneven-age forests. Within the group, regeneration occurs as a single age class rather than mixtures of age classes as in single-tree selection.

Operational Obstacles Associated with Sustaining Uneven-age Structure

Disturbances that occur in southern forests, either anthropogenic (human-caused) or natural disturbances (tornados, hurricanes, wind, ice, insects, disease, fire) are common and frequent. These disturbances usually produce larger openings in the forest canopy where shade-intolerant species regenerate. These larger openings cause more even-age regeneration and disrupt the development of small or group openings characteristic of uneven-age stands. The frequent, larger-scale disturbances promote even-age stands rather than uneven-age.

The progression of trees growing into larger size classes is a prerequisite of the uneven-age system. Trees are cut in each size class to ensure the progression. Generally, the undesirable species and poorly formed trees are harvested during the cutting cycle and the best are retained. The best and largest trees are only harvested when trees with better growth potential can replace them. Carelessly cutting only the best trees is a sure way to

Major Advantages and Disadvantages of Uneven-Age Silviculture
(Modified from Nyland 2002)

Advantages

1. A balance of three or more age classes is maintained in perpetuity.
2. Well-distributed tree cover with several strata.
3. Large-diameter trees are always present to ensure some sawtimber volume growth, a steady supply of timber and opportunity for income at frequent intervals.
4. An abundance of reproductively mature trees ensures a source for regeneration.
5. Trees with steady rates of radial increment are present in all size classes and are continually upgraded to have high value at maturity.
6. Intermixing of size classes makes stands picturesque to many viewers, and well-suited to many forest objectives.

Disadvantages

1. The stand must be inventoried in each cutting cycle to determine diameter distributions and growth. Greater skill is required to maintain a balance among size classes.
2. Short cutting cycles increase the frequency of site disturbance. Because of the interspersion of different size classes, some of the residual trees and reproduction suffer logging damage, even with careful harvesting.
3. Shade-intolerant species commonly fail to reproduce in the shade reducing the diversity of the plant community.
4. Frequent entry for harvesting requires an elaborate network of carefully planned skid trails and access roads.
5. Contractors incur high logging costs to remove widely dispersed sawtimber trees so revenues to landowners are reduced.
6. Stands with an excess of small or unmerchantable trees must be tended and this work can be cost-prohibitive.
7. The uneven-age system provides poor habitat for animals that depend upon early-succession plant communities.
8. Several cutting cycles are required to establish multiple age classes and size classes to create uneven-age structure.

deplete the future productive potential of the stand. Unfortunately, this is common when high-grading or diameter-limit harvesting is practiced in the name of uneven-age systems.

With more frequent entries and shorter cutting cycles, residual trees are more prone to logging damage, even with careful harvesting. The re-entry and harvest of the stand at relatively short intervals leads to a greater chance of injuries to sapling and pole-sized trees, resulting in a loss of tree quality and stand value over time. Since cutting cycles are more frequent, lower volumes are harvested at each entry. An elaborate network of roads and skid trails are maintained with recurrent entries, increasing the frequency of site disturbance. These frequent entries and lower volumes harvested suggest that economic feasibility of the uneven-age system in southern hardwoods is questionable.

Growth and Production of Uneven-age Stands

A debate continues comparing the productivity of even-age versus uneven-age systems. The dispute tends to be an exercise in evaluating many discrete concepts such as regeneration under continuous forest cover, the various stocking levels associated with each system, comparison of different species with different shade tolerances and growth rates, site utilization, and greater timber values versus volume accumulation that are difficult to compare. Considering that there are so many variables to assess (site quality, management intensity, rotations versus cutting cycles and relative time periods), the literature reveals no trend for one system or structure being more productive than the other.

Variable Retention

Uneven-age management provides variable retention of trees that can be advantageous for certain management objectives. Variable retention is defined as retaining structural elements or biological legacies (trees, snags, logs, etc.) in the harvested stand for integration into the new stand to achieve various ecological objectives (Society of American Foresters 1998). While uneven-age methods can help meet some variable retention objectives, other systems or methods can also be conducive for these objectives, such as two-age systems (Stringer 2006a) and legacy trees (D'Amato and Catanzaro 2007).

Aspects of variable retention are becoming important, and since uneven-age methods have been touted as being able to achieve some of these retention objectives, a discussion of variable retention is included.

Variable retention has been championed in the Pacific Northwest (primarily British Columbia and Oregon) and in Finland as a method to ameliorate the visual appearance of clearcuts. Large trees are used to provide some structural diversity and eventually coarse woody debris that would not be present if a complete clearcut is used. However, the science behind tree retention is at best limited. Should trees be left singly or in groups? What benefits are being addressed biologically as well as economically with tree retention?

Moore (1999) indicates that variable retention is based on the concept that the most important value in the forest is biodiversity, the many species of plants, animals, birds, insects and invertebrates living there. To make sure that all the species can survive in a managed forest, it is necessary to understand their habitat requirements for breeding, feeding, hibernating, etc. So long as sufficient habitat is retained on the landscape, populations of each species may be maintained. Birds that nest in shrubs will usually find more available shrubs where the forest cover is altered. Other species, such as cavity-nesting birds, need standing dead trees in the landscape, and still others need fairly large blocks of older forest. Variable retention is about planning timber harvesting over time so that all the necessary features for species survival are always present somewhere in the landscape. Uneven-age systems may be appropriate for such objectives.

Variable tree retention is practiced in the western United States as a method to maintain a wider range of biodiversity in large-area harvests (hundreds of acres) in stands of one or few number of species. The positive overtones of variable tree retention have been transferred to the eastern United States. However, is variable tree retention needed to maintain biodiversity in eastern forests? Considering that most harvests in the eastern US are less than 100 acres, that eastern forests are composed of many species on a varied landscape and the faster rate of response after forest disturbance, variable tree retention is probably not necessary to maintain biodiversity in eastern forests. The scale of disturbance and response is not as great as in western forests. Some animal, insect and invertebrate species may be displaced by harvests for a short time, but adjacent forests usually can continue to provide these habitat conditions such that biodiversity is sustained.

To some degree, variable tree retention is already practiced in the eastern United States. Standard practices such as streamside management zones (SMZs), visual buffers and islands of vegetation left in the harvest area to maintain undisturbed or unique areas have attributes of variable tree retention. The smaller ownership size of forests also contributes to the wider range of landscape diversity.

In Tennessee, variable tree retention is not a new concept. Unpublished forest research by the USDA Forest Service at Sewanee, TN in the late 1970s left 10 or so mature trees per acre in an attempt to ameliorate the visual aspects of a harvested area. While the public was appreciative of the visual effects of leaving a few trees in the harvest area, the remaining trees actually declined in value, some single trees died due to increased exposure and the trees negatively influenced the development and composition of regeneration in the shade of the tree crowns.

Forest managers should consider the purpose of variable tree retention within the scale of their management operations. Trees to maintain visual quality, to implement a two-age or uneven-age form or to uphold vertical forest structure on the harvested area are positive attributes of variable tree retention. However, tradeoffs common with the uneven-age system are also prevalent, such as damage to residual trees during harvest, potential decrease in value of remaining trees and the impact of those trees on the development of regeneration. Many aspects of variable tree retention are already in place with SMZs, visual buffer areas and in protecting unique topographic and vegetation areas.

Variable tree retention may sound better than its actual contribution to landscape biodiversity, especially in the smaller harvests and diverse landscapes in hardwood forests. As with all forest management activities, forest managers and landowners should evaluate the positive attributes, as well as the trade-offs with variable tree retention and make decisions based on management objectives. Variable tree retention is another one of the subjects that may not have universal application, but is a tool that can enhance forests and management under specific circumstances.

Research Examples of the Uneven-age System

Single-tree selection and maintaining uneven-age structure has been successfully practiced on the Pioneer Forest of the Missouri Ozarks (Flader 2004). These xeric sites allow growth and regeneration of oaks with single-tree selection regeneration, because the area does not support more mesic, competing species that may interfere with oak regeneration and development. Oak reproduction tends to accumulate and recruit to successive age classes on these sites without the presence of species (maples, blackgum, sourwood, beech) with potential to develop a heavy midstory or species such as yellow-poplar with the capacity to outgrow oak. Stable, long-term ownership and markets that facilitate the removal of small volumes of logs are present. Usually one to three cutting cycles (30 to 50 years) are required to achieve uneven-age structure (Loewenstein and Guldin 2004). During this time, income from the forest is limited and management expenses are incurred. On the majority of hardwood sites in the southeastern United States, the diversity of species and need to control shade-tolerant and midstory trees species are serious disadvantages to implementing single-tree regeneration practices if the objective is to regenerate and sustain shade-intolerant species.

Single-tree selection has not been proven as a successful tool in regenerating desirable species (primarily oaks) in the southern Appalachians on more mesic sites. A long-term study initiated in 1946 and conducted by Della-Bianca and Beck (1985) in western North Carolina suggests that even though a reverse J-shaped or negative exponential curve can be created, the smaller diameter classes are composed of midstory, tolerant trees such as dogwood, sourwood, blackgum and hornbeam --- non-commercial species that will not ensure the future sustainability of the stand. Significant use of herbicides is required to control competing midstory vegetation allowing establishment and growth of advance regeneration of desired species. Single-tree selection may have some application on xeric sites on the flat surface of the Cumberland Plateau similar to those of the Pioneer Forest where there is limited influence from competing species in the understory and midstory (Schweitzer et al. 2004). For more productive areas, a shelterwood technique has been developed to promote oak regeneration while controlling competing midstory regeneration (Loftis 1990; 2004; Stringer 2006b).

Summary

The intent of the uneven-age system and the use of single-tree selection for regeneration are to create a self-sustaining forest in which trees of many sizes and ages are present and intermingled with each other. Evidence and research indicate that uneven-age structures can be problematic to develop and maintain in hardwood ecosystems in the southern United States. Concerns about the uneven-age system in southern hardwoods are as follows.

1. Favors tolerant species
2. Less valuable sawtimber produced due to less valuable species composition
3. Cost of operations is more and a larger land area is impacted by harvesting
4. Entries with shorter cutting cycles provide greater opportunity for damage to residual trees and site disturbance
5. For management to be effective, must cut in all size/age classes during each cutting cycle to ensure growth and progression to larger-diameter classes
6. Markets for small-diameter products must be available to economically use the system. Low volumes harvested during frequent cutting cycles generally are not economically attractive

A typical high-grade forest leaves poorly formed, inferior growing stock for future growth.

7. Serious danger of degenerating to high-grading and diameter-limit cutting unless proper care is taken to promote all size/age classes and create conditions for regeneration during each cutting cycle or entry

8. A fairly long time period of several cutting cycles is required to achieve and maintain uneven-age structure. Unfortunately, forest disturbances are common preventing the uneven-age structure from developing and being maintained.

Application of the uneven-age system is complex and requires careful evaluation, interpretation of inventories, skill and effort. Economics of instituting and maintaining uneven-age stands is not favorable. Considering that few shade-tolerant hardwood trees are economically valuable in southern hardwoods and that disturbances occur frequently on the landscape, many of the advantages of the uneven-age system are not attained and often harvests degrade into more exploitive high-grade or diameter-limit harvests.

Uneven-age structure can be created without the strict adherence to creating and maintaining three or more age classes in the uneven-age system. Stratified, even-age stands are common in hardwood stands that have several size classes that simulate the reverse J-shaped diameter distribution. Different species in mixed stands grow at different rates although the trees are of similar age. Thus, these stratified stands have uneven-age attributes, but are even-age, having been established after a disturbance event.

In small woodlots of several acres, the uneven-age system can be practiced by making sure that stems continue to progress from one size class to another. Management is by individual stems, not the stand level. Each stem can be given the favorable environment for it to succeed in becoming a mature tree by continually monitoring and arranging its growing space. Management is very intensive and cannot be reasonably accomplished on larger acreages because of the excessive time and effort in managing individual stems. However, many of the attributes of the uneven-age system (primarily visual) can be attained on small acreages through individual tree management as long as regeneration is created during each harvest.

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