Group Selection—Problems and Possibilities and for the More Shade-intolerant Species

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Abstract: The group selection method is a hybrid, drawing key elements from both even- and uneven-aged silviculture. It is perhaps the least used and understood of all the reproductive cutting methods, but it is gaining popularity because of the current disfavor of even-aged silviculture. The group selection method appears promising for regenerating shade-intolerant and intermediate-tolerant species. Research has shown that larger openings create conditions favorable to shade-intolerant species, while smaller openings favor the more shade-tolerant ones. Larger openings consist of a central core that is relatively unaffected by the adjoining stand and a periphery with increasing levels of suppression. Operationally, most opening widths vary around one to two times the dominant tree height in the residual stand, but research has yet to verify the long-term stand dynamics within openings. Even less is known about effective stand-regulation options available to provide sustained yields. One route is to adapt stand structure or volume control from the single-tree selection system. An alternative is to use (1) the silvical requirements of the target species to set opening size and (2) area control to determine the number of openings to create each cutting cycle. This latter approach seems to have advantages for applications in even-aged stands that are being converted to uneven-aged ones.

INTRODUCTION

Group-selection cutting has been a much debated but heretofore little used reproduction method. It has been advanced as a viable technique and vilified as impractical and difficult to maintain. Marquis (1978) described group selection as a "bastard" technique that attempts to meld an even-aged reproduction cutting method with an uneven-aged silvicultural system. Roach (1974) called it a modification of single-tree selection to favor reproduction of less shade-tolerant species. Interest in the group selection method has been revived recently because of controversies surrounding even-aged reproduction methods, especially clearcutting, and the apparent shortcomings of the single-tree selection method for regenerating certain species.

Although clearcutting is a proven, efficient reproduction method for many species, its use has been sharply curtailed because of public sensitivities to the dramatic visual impact of a recent clearcut. This criticism of clearcutting has occurred not only in the United States, but also in other countries (Bradshaw 1992). The outcry about clearcutting on public lands has resulted in its complete abandonment in some cases and a more circumspect use in others--such as reducing the size, blending the cuts with the landscape, and masking their size by employing convoluted shapes. The other even-aged methods, seed tree and shelterwood, would seemingly ameliorate the drastic perturbation of clearcutting and still provide some of its efficiencies. However, they have suffered a "guilt of association" by being even-aged methods.

The single-tree selection method has been proposed as an alternative to clearcutting, especially by environmental groups, because it appears to be the antithesis of the much despised clearcutting.

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However, it has limitations like any cutting method. If applied to even-aged stands, the smaller trees may be the same age as ones in the overstory and may not respond to release. Also, if practiced with no competition control, shade-intolerant species will be gradually replaced by shade-tolerant ones in the understory. This has been a common outcome with trials in eastern hardwoods.

The fallen repute of even-aged cutting methods plus the limitations of single-tree selection when administrative restrictions are imposed have made group selection the choice by default for many public lands. However, operational use has been virtually nonexistent until recently, and research has focused mostly on the establishment and development of regeneration within openings. Many questions have not been studied or only fragmentary information is available: how should the residual stand be managed; the distribution, optimum size, location, and shape of openings; the need for site preparation both in openings and the residual stand; and how the stands should be regulated. Opinion differs about what constitutes the group selection system and what regulation techniques are appropriate.

In this paper, we explore these issues by examining existing literature concerning what group selection is, how it differs from single-tree selection and closely allied even-aged cutting methods, how regeneration of desirable species might be obtained by appropriate opening designs and site preparation techniques, and the alternatives for stand regulation. We also focus on the application of group selection to the more shade-intolerant species, which are usually targeted in central and southern stands. Because of this focus, a broader definition of group selection has been adopted in this paper than has been proposed elsewhere (Marquis 1989, 1992).

CONCEPTS AND DEFINITIONS

We paraphrased the following definitions from Smith (1986):

> Even-aged stand—a stand that is composed of one or two age classes, and the range of tree ages in an age class does not span more than 20 percent of rotation length.
>
> Uneven-aged stand—a stand that is made up of at least three age classes, where an age class is defined as for even-aged conditions.
>
> Reproduction method—is how a stand is established or renewed. An uneven-aged cutting method will regenerate or create an uneven-aged stand.
>
> Silvicultural system—the planned sequence of silvicultural activities that are designed to create and/or maintain either even- or uneven-aged stands.
>
> Single-tree selection method—is a reproduction cutting method used to regenerate an uneven-aged stand and consists of removing mature trees as scattered individuals or as small groups at relatively short intervals.
>
> Group selection method—is a reproduction cutting method used to regenerate an uneven-aged stand by removing groups of adjacent trees at relatively short intervals.

From these definitions, the group selection system includes the following: (1) using the group selection method to create new age classes, (2) applying appropriate site preparation, release of advance regeneration, or tending of immature trees within openings, (3) tending the remainder of the stand, and (4) employing a regulation technique to assure a balanced structure and sustained yield.

Group Selection vs Single Tree Selection

If a strict interpretation is made of the definitions of single tree and group selection, then the single-tree method involves removal of scattered mature trees, and the group selection method entails the removal of two or more adjacent mature trees. Nyland (1987) makes this distinction for northern hardwoods. However, harvest of only mature trees (whether they occur singly or in groups) may not result in openings that are large enough to meet the silvical requirements of the target species, especially the more shade-intolerant ones.

Marquis (1989, 1992) has a somewhat different interpretation of group selection as applied to northern hardwoods. Group openings are created in areas where several trees need to be cut for quality, size, vigor, or other factors; they need not be mature. The openings are usually small, about 0.1 to 0.25 acres, but may occasionally reach 0.5 acres. Groups are made to increase the representation of shade-intolerant species, but not necessarily to maximize their percentage.

We prefer to focus on how mature trees are selected for harvest as a way to differentiate between the single tree and group selection methods. In single tree selection, trees are selected for harvest largely based upon their individual merits, such as financial or biological maturity. Because trees tend to occur in small, similar clumps, a group of trees may be cut under single-tree selection, but each tree was chosen individually.

The single-tree selection system has been successfully adapted to more shade-intolerant species, such as the loblolly-shortleaf pine type (*Pinus taeda* and *P. echinata*, respectively), by following certain principles and practices: (1) a target species or species mixture that is moderately tolerant in the seedling stage, (2) maintaining a residual basal area low enough to permit the establishment and development of desired reproduction, (3) choosing a cutting cycle to keep basal area levels within acceptable ranges, (4) eliminating overstory and midstory non-target competition by harvesting or manual and/or chemical treatment, and (5) periodically controlling understory non-target competition (usually with selective herbicides). The combination of a low basal area (one that does not exceed 75 square feet per acre at any time during the cutting cycle) and competition control results in an environment favorable for development of pine regeneration.

Under these conditions, a quite different forest mosaic occurs than the popular conception of a continuous forest cover with an occasional small opening created by the removal of a single tree. For example, the canopy is quite irregular and broken in loblolly-shortleaf pine stands managed under the single-tree selection system. Immature clumps of pines are interrupted by groups of pulpwood and sawtimber, occasional lone specimens of larger trees, and recently created openings that can range up to 0.5 acres in size. According to a strict interpretation of the definitions, both single tree and group selection methods have been used under this management. But we think that this strict interpretation results in a misleading explanation of the system. A combination of both stand structure control and a low residual basal area results in the creation of gaps or openings of various sizes. However, these openings were not purposely created by consciously trying to create an opening at a specific location.

In the group selection method, the choice of trees for harvest focuses on groups of trees rather than individuals. Groups are selected for harvest based on their aggregate condition: Are most of the trees in the group financially mature? Should they be removed because of damage inflicted on the group? Are most of the trees likely to die if they are not cut now? Is the group poorly stocked with little likelihood of becoming well stocked with the existing trees? According to this interpretation, selection of a group includes not only mature trees but also other trees within the area.

The choice of single-tree versus group-selection depends upon how the advantages of each cutting method fits management objectives. The advantages of single-tree selection are: (1) regulation is easier, (2) better visual quality because of absence of large openings, (3) greater stand homogeneity, and (4) possibly a better yield and quality of timber. Group selection has the following advantages: (1) provision of better regeneration microsites, (2) herbicide applications can be confined to less area, (3) more intensive site preparation can be used, (4) existing regeneration is easier to protect, (5) a diversity of habitats for plants and wildlife is created, and (6) mixed-species stands (especially intolerant-intermediately tolerant mixtures) are easier to maintain.

Group Selection vs Patch Clearcutting

Group selection might also be confused with clearcutting that is confined to small areas of several acres. Though these even-aged stands might be small, they will retain their integrity, and a silvicultural program for these stands will be a sequence of well defined activities suitable for even-aged stands. For administrative purposes, their identity will be preserved by silvicultural treatments and mapped as regenerated for regulation purposes. In contrast, the location of openings in group selection is not known. In addition a principal goal of group selection is to create an uneven-aged stand with its characteristic reverse J-shaped stand structure.

If openings exceed 0.5 acres in size in northern hardwoods, Marquis (1989, 1992) states that the resulting environments become more like those in clearcuts, and he calls the system patch cutting. Smith (1980) makes a similar interpretation for central Appalachian hardwoods. However, differentiating between group selection and even-aged methods based upon only opening size is somewhat arbitrary. Bradshaw (1992) proposed that the distinction lies in the proportion of the opening that is influenced by edge effect. Openings in uneven-aged silviculture are dominated by edge effect, while the unaffected core dominates the openings of even-aged silviculture. The extent of edge effect depends on the opening size and shape, the height of the residual stand, the silvical requirements of the target species, and topography.

Perhaps a better limit might be scaling opening size according to the residual stand height. Smith (1986) has suggested openings whose diameter is twice the height of the surrounding stand. If this limit is accepted as a guide, then openings could reach up to an acre in size in eastern forests (Figure 1). However, most openings will probably be smaller because stand heights will typically be less than 100 feet. Thus, adopting two times the height of the surrounding stand as the upper limit for group selection may result in slightly larger openings than the 0.5 acre limit proposed by Marquis (1989). Openings that far exceed this limit of two tree heights are being created for administrative efficiency, logging costs, or other reasons; the rationale for opening size has ceased to be motivated by environmental conditions.

The silvical requirements of target species must also be considered in determining a suitable opening design. Some shade-intolerant species may need openings somewhat larger than two times tree height to provide an acceptable distribution of edge effect, while more shade-tolerant species may require smaller openings. In application, opening size and configuration is a compromise between the existing group of trees and the regeneration requirements of the desired species. For example, the size of the extant group might be 0.2 acres, but the silvical characteristics of the species might require a larger opening.

As noted by Minckler (1986, 1989), some foresters think of group selection as a mechanical placement of openings up to 2 acres in size with openings near the upper size limit being generally favored. Clearly, such a systematic arrangement of openings is not based upon stand conditions and may not address the silvicultural needs of the stand.

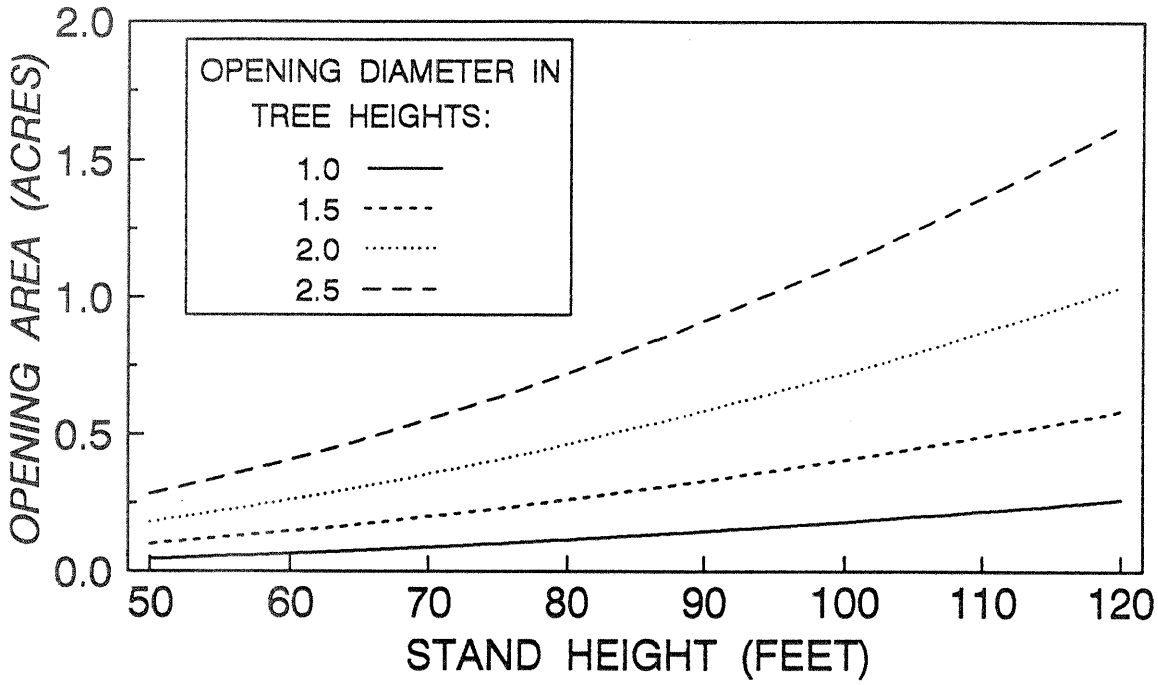

Figure 1.—Group opening size as affected by surrounding stand height and required opening diameter.

Variants of Group Selection

The group selection system may be viewed as a whole suite of variations that can be separated only with difficulty and by use of a complicated terminology (Smith 1986). Such variation taxes our silvicultural nomenclature but adds flexibility to the system. Vigorous, immature trees can be left in the openings as future growing stock, while removing low-quality material (Minckler 1986, 1989). Seed trees might also be retained much as in the seed tree or shelterwood methods. These trees enhance seed production, provide shelter, and improve visual properties.

REGENERATION

Opening Size, Shape, and Location

A basic concern in applying the group selection method is the opening size necessary to secure acceptable reproduction of desired species. Most past research focused on the development of reproduction within openings. It has clearly shown that shade-intolerant species develop better in large openings and that shade-tolerant species dominate small openings (Bradshaw 1992).

The area within an opening that is influenced by the surrounding stand depends on: (1) size, shape, and orientation of the opening, (2) height, density, and species composition of the edge trees, and (3) slope and aspect. Marquis (1965) reported that shape and orientation have little effect on the average exposure to direct sunlight occurring in 0.1-acre openings, with values ranging only from 22 to 26% (Figure 2). However, shape and orientation had an important effect as opening size increased. For 0.5-acre openings, a rectangular shape with north-south orientation has the lowest average exposure to direct sunlight (44%), while one with an east-west orientation

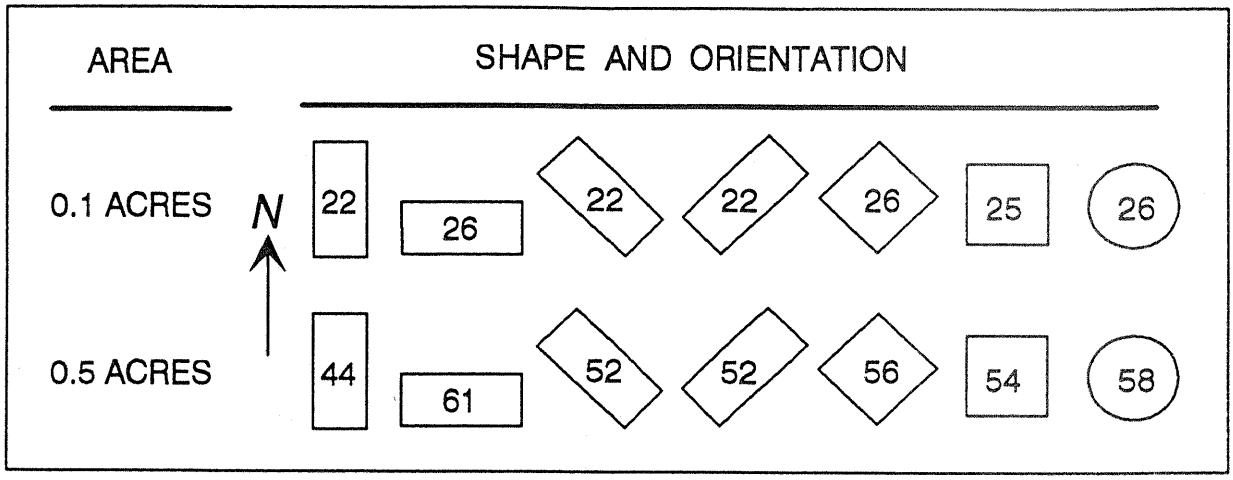

Figure 2.—Average direct sunlight exposure (percent) occurring in various opening sizes, shapes, and orientations (after Marquis 1965).

had the greatest (61%). Thus, narrow openings with a north-south orientation may not create light conditions necessary for shade-intolerant or intermediate-tolerant species. Describing the effects of slope on the direct solar radiation occurring in openings, Fischer (1979) found that values for a 30% slope on a north aspect were about one-third less than for an identical slope with a south aspect. Thus, north-aspect openings need to be larger than ones on a south aspect to have comparable values of solar radiation. In application, openings with straight boundaries and angular corners have harsh visual properties, and preferred shapes are circles, ellipses, ovals, teardrops, kidneys, and amebas.

Opening size and shape affect reproduction survival and growth of shade-intolerant species, such as loblolly and shortleaf pine (Wahlenberg 1960; Jackson 1959). Survival and height growth are greatest in larger openings, and circular openings have higher values than irregular ones (Figure 3A and 3B). Wahlenberg (1960) reported that the edge of a young sawtimber stand influenced the development of reproduction up to 30 feet into adjacent openings. Six-year-old seedlings beyond 30 feet from edge trees were twice as tall as those within 10 feet (4.5 versus 9.1 feet). The amount of an opening unaffected by edge trees increased with opening size, and was 4 to 12 times greater in circular openings than irregular ones of the equivalent size (Figure 3C). Thus, small circular openings provide a better environment for shade-intolerant reproduction than much larger ones of irregular shape. A 0.8-acre circular opening has one half of its area affected by surrounding trees; smaller openings are dominated by this edge effect, while larger openings are dominated by the unaffected core (Figure 3C).

Advance oak reproduction growth in the center of openings with diameters as small as one or two tree heights is similar to that observed in large clearcuts (Minckler and Woerheide 1965; Sander and Clark 1971; Smith 1980, 1981). However, smaller openings have a high proportion of area affected by edge trees and will hinder the development of the more shade-intolerant species (Sander and Clark 1971; Sander and others 1983; Smith 1981).

Finding opportunities to create openings within a stand requires paying close attention to stand conditions and terrain features. Unless stand conditions are very uniform, openings should not be mechanically spaced. Opening location should be based on both overstory and understory conditions. Suitable locations include: (1) groups of mature trees, (2) areas with poor stocking and/or low quality trees, and (3) areas with good advance reproduction, especially for the oaks.

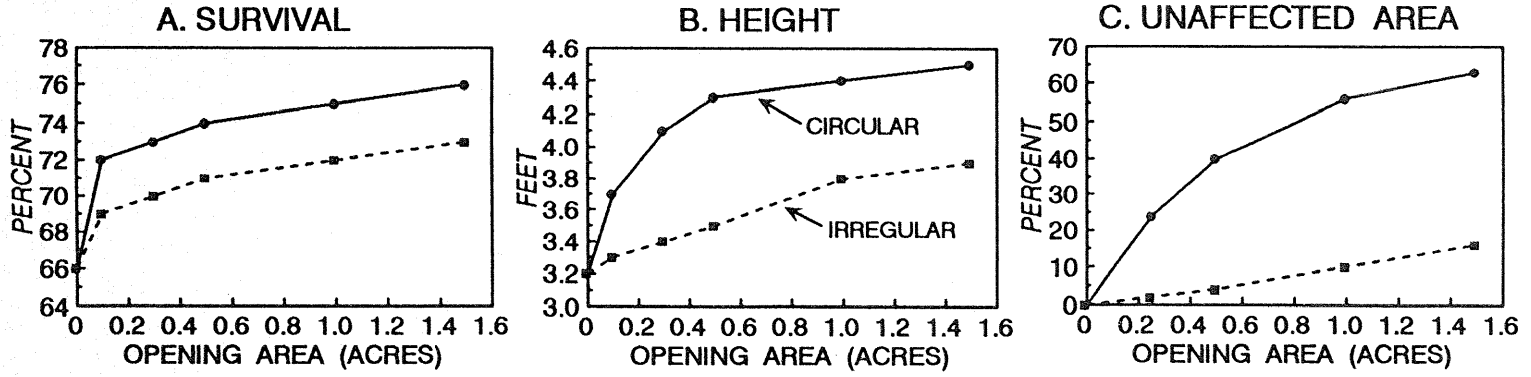

Figure 3.—Effect of opening size and shape on (A) survival and (B) height of 5-year-old pine regeneration and (C) the percent of total area unaffected by the surrounding stand of young pine sawtimber (after Wahlenberg 1960).

Reproduction Options

The group selection method establishes openings in the canopy to create a favorable environment for desired species. Successfully regenerating these openings is critical for long-term stand sustainability. A principal factor affecting reproduction success is the shade tolerance of the targeted species.

Shade-Intolerant Species

The group selection method seems to have potential for regenerating a wide variety of the more shade-intolerant species, such as ashes (*Fraxinus* spp.), black cherry (*Prunus serotina*), loblolly pine, shortleaf pine, sweetgum (*Liquidambar styraciflua*), and yellow-poplar (*Liriodendron tulipifera*). These species typically regenerate from wind-disseminated seeds and grow poorly in the shade. They frequently regenerate naturally in the resource-rich environments existing after major stand disturbances. Reproduction can develop from several sources depending on (1) when a disturbance occurs, (2) the annual variation in seed production, and (3) the species silvical characteristics. Possible sources include in-place seeds, seeds disseminated by nearby trees, advance reproduction, and stump sprouts for some species. Reproduction from in-place seeds is important for species such as yellow-poplar, whose seeds remain viable for 4 to 7 years in the forest floor (Clark and Boyce 1964). For species with short-lived seeds, reproduction from in-place seeds will be opportunistic, and most reproduction will probably come from seeds dispersed from nearby trees while seedbed conditions remain receptive. Thus, an adequate seed source of desirable species is usually important when locating openings. The maximum down-wind seed dispersal for acceptable reproduction is 200-300 feet for loblolly pine (Pomeroy 1949), 200 feet for sweetgum (Kormanik 1990), and 200 feet for yellow-poplar (Beck 1990). Consequently, wind-disseminated seeds should adequately regenerate the central portion of the largest openings proposed under the group selection method if there is a seed source. Animal dissemination will be crucial for certain shade-intolerant species, such as black cherry.

Surface disturbance enhances the seedbed conditions for some shade-intolerant species, such as loblolly and shortleaf pines. For such species, skid trails could be routed through openings if terrain and soil features are not limiting. Although successful natural reproduction can be obtained with logging conducted anytime during the year, the optimum time is just before seed dispersal, which assures a receptive seedbed.

Planting is a viable option within openings where conditions do not favor natural reproduction (Waldrop 1991). However, costs per unit area may be higher than for typical even-aged operations, because of inefficiencies associated with planting small scattered openings. Direct seeding may also be an alternative for some species (for example, the pines).

Intermediate-Shade Tolerant Species

Group selection method has potential for regenerating species of intermediate-shade tolerance, such as oaks (*Quercus* spp.) and hickories (*Carya* spp.). We will focus on the oaks because they are the premier representatives of these heavy-seeded species. Natural oak reproduction in both openings and in the residual stand will consist of new seedlings, advance reproduction (older seedlings and sprouts), and stump sprouts of harvested trees. New seedlings are not a viable source of oak reproduction, because they grow too slowly and other vegetation usually overtops them within a few years (Beck 1970; McQuilkin 1975; Sander 1972). Thus, well-developed, advance oak reproduction or small stems with sprouting potential must be present before overstory removal if oaks are to become an important component in the new stand. Height growth of oak stump sprouts is rapid, and they usually grow into upper crown positions in the new age class

after overstory removal (Johnson 1977, 1979). However, the probability that an oak stump will produce a dominant or codominant stem decreases with increasing tree diameter and age (Johnson 1977). Stump sprouts can be an important source of oak reproduction in many upland hardwood stands on medium and poor sites. Mature stands on these sites usually contain a relatively large number of small-diameter oak stems that will sprout after cutting. By contrast, mature stands on more productive sites have few small-diameter oaks, and the larger trees will not sprout sufficiently to regenerate an adequate oak component after cutting.

In most cases, advance reproduction will be the primary source of any dominant and codominant oaks that develop in openings. However, the presence of advance oak reproduction alone does not guarantee success. Advance reproduction must be relatively large and have well-established root systems (Carvell 1979; Sander 1972, 1988; Sander and Clark 1971). Growth of advance reproduction following cutting is strongly related to its size before harvest (Sander 1971, 1972). The probability that an individual oak stem will become a dominant or codominant increases with increasing basal diameter and height, but even larger stems may not succeed on higher quality sites (Loftis 1990a; Sander and others 1984).

Advance oak reproduction must also be established throughout portions of the stand for future openings. Proposed procedures are similar to the shelterwood method for oaks, and involve regulating overstory stocking and controlling midcanopy and understory competition (Sander 1987, 1988; Loftis 1990b). The time required to establish oaks and grow them to an adequate size as advance reproduction is not known, but could vary from 2 to 20 or more years. Where natural oak advance reproduction is inadequate, planting can supplement existing reproduction within the stand or in poorly stocked openings. A technique developed for the Missouri Ozarks involves planting large caliper 2-0 stock under a shelterwood overstory 3 to 5 years before overstory removal. Subcanopy control is needed at planting, and on productive sites a second treatment may be required at the time of overstory removal (Johnson 1984; Johnson and others 1986).

Another approach currently being tested is the placement of plastic sleeves, or tree shelters, around planted seedlings. Tree shelters protect seedlings from browsing and improve the microclimate within the shelter. Their use with oak planting in Britain has quadrupled height growth in the first 4 years (Potter 1988).

Effects of the edge trees may complicate the evaluation of oak reproduction potential in openings. Present guidelines were developed for large clearcuts (Loftis 1990a; Sander and others 1984) and may not suffice for smaller openings. Successful development of oaks in smaller openings may require larger advance reproduction than necessary for clearcuts and/or more intensive competition control.

Mixed-Species Stands

Compositional gradients will likely develop within openings, with shade-intolerant species dominating the opening center and the more tolerant species dominating the edge. This may be a blessing or a curse depending on silvicultural objectives. The natural segregation of species across an opening would be ideal in establishing pine-hardwood mixtures, due to their differential growth rates. Pines tend to dominate natural even-aged stands, where overstocking frequently occurs. A pine-hardwood composition could also be favored by establishing a range of opening sizes, with the pines tending to dominate the larger openings and hardwoods the smaller ones.

Competition Control

Without species control, the application of uneven-aged silviculture in stands of the more shade-intolerant species will usually cause a gradual shift in composition to more shade-tolerant ones.

This is a major limitation in using this system to create or maintain in uneven-aged stands of the more shade-intolerant species (Blair and Brunett 1976; Franklin 1978). Competition control may help to preclude this species shift.

Operational application of competition control has not been widely tested in small scattered openings. Undoubtedly, it will be less efficient than stand level-treatments, and contractors will need compensation for the time required to locate and travel between openings. Locating openings will be easiest in the first dormant season following logging when visibility is a maximum. There is also some potential to link the harvesting operation and control of unwanted submerchantable trees by either chain-saw felling or using skidders as shears. The extent to which manual and mechanical methods can be substituted for herbicides is unknown, especially on better sites.

Shade-Intolerant Species

Competition control for species regenerating from seed should occur after the logging and be limited to well-defined openings. It may be required every cutting cycle. The need for competition control in openings will vary with seed production, merchantability of small trees, harvest volumes, and understory condition. Because harvest volumes in group selection cutting are more concentrated, seedbed disturbance from logging will typically be greater than with single-tree selection cutting. Logging will often provide sufficient surface disturbance to establish adequate stocking of shade-intolerant species requiring a scarified seedbed, although subsequent release may be required. In addition to treating current openings, release work may be required in previously established openings. Broadcast applications of selective herbicides are an option in pine stands. However, competition control for shade-intolerant hardwoods or pine-hardwood mixtures will be limited to individual-stem treatments.

Intensive mechanical methods of site preparation can be used within group openings for both seedbed preparation and competition control (McDonald and Fiddler 1991). However, they should probably be restricted to stands with severe competition problems, because excessive stocking may occur.

Intermediate-Tolerant Species

Competition control involves treating portions of the residual stand to secure the advance oak reproduction needed for future openings, as well as releasing advance reproduction in the openings. Competition control can include a full array of herbicide treatments of individual stems--basal and foliar sprays and cut-surface applications. Operators must be able to identify the tree species targeted for control.

Competition control in the residual stand is similar to that done in the shelterwood method. Treatments must be intensive due to the slow response of oak reproduction and the rapid development of other species (Hannah 1987). Recommendations for shelterwood stands in the southern Appalachians call for killing all noncommercial stems larger than 0.6 inch d.b.h. (Loftis 1990b). On highly productive sites, this will yield relatively few dominant or codominant oaks but will ensure an oak component in the new stand. For productive mesic sites in the Central hardwood area, competition control may have to be even more intensive. Sander (1987, 1988) recommends killing at least the competitors more than 6 feet tall, but preferably all competitors.

The need to release oak reproduction will depend on the intensity of previous competition control measures, opening size, and site quality. Intensive competition control applied years before creating openings may reduce or eliminate the need for later treatments. If there is adequate large oak

advance reproduction, cutting or killing stems larger than 1 or 2 inches dbh should suffice (Sander 1988). More productive sites may require more intensive competition control. In small openings, the edge trees may retard oak reproduction growth, which might reduce oak stocking. This may necessitate more intensive release, especially on the more productive sites.

Protection

The selection system involves periodic harvest of mature trees intermingled with younger trees, and logging will damage or destroy some of them. This potential damage has long been recognized in uneven-aged stands where multiple size classes are interspersed (MacKinney 1934). Damage was of little concern during the days of animal skidding or small skidders. However, current emphasis on logging efficiency (large skidders and tree-length logging) has raised the specter of more severe damage to both reproduction and merchantable trees. The group selection method offers some degree of protection by concentrating reproduction to well-defined openings (Guldin 1991). Logging contracts could be written to preclude logging activity in areas with young reproduction. In highly controlled circumstances, a limited amount of skidding through openings overstocked with reproduction might be used for precommercial thinning. Skidding damage can also be important in the residual stand, especially in hardwoods where damage to the lower bole can result in rot and other defects that can reduce tree value.

Because of the intermingled size classes, fire protection is critical in uneven-aged stands of either pine or hardwood. However, an interrupted-prescribed burning cycle could potentially be used in pine stands under group selection if long cutting cycles are used (Chapman 1942). Prescribed fires could start as soon as reproduction within openings reaches fire-tolerant sizes, and burning would stop when a new series of openings are created. However, because of the heterogeneous stand conditions, the use of prescribed fire will never be as simple as in even-aged stands.

REGULATION

Regulation in uneven-aged stands is a complex topic, and our goal here is to briefly discuss its role in uneven-aged silviculture and how it can be used in the group selection system.

We begin with some definitions adapted from Davis and Johnson (1987):

> Regulation—as it is traditionally defined is the management of a forest to provide a sustained, even flow of timber or other products. However, regulation is also applied at the stand level in the selection system.
>
> Area control—is a method of regulation in which a sustained yield is provided by harvesting and regenerating the same amount of area each period.
>
> Volume control--is a method of regulation in which the harvested volume for each period is based upon the growing stock level and its distribution and growth. A growing stock level is chosen so that a sustainable periodic cut is achieved.

A fully regulated forest has been regarded as one in which a sustained and even yield has been achieved in perpetuity. Both Davis and Johnson (1987) and Smith (1986) state that the whole concept of regulation has become more flexible, because (1) most landowner objectives change with each planning period and (2) many forests are managed to provide both a flow of timber and other forest products under performance criteria and constraints that often change.

Both area and volume control have been used for even-aged forests. Area control can provide a fully regulated condition by the end of one rotation, but annual yields during the conversion period may vary. If relentlessly pursued, other landowner objectives may be sacrificed to achieve a fully regulated forest. Volume control ameliorates fluctuating yields by providing more stable harvests, but a fully regulated condition may not be achieved in one rotation. In practice a combination of the two methods has been used, and modern scheduling techniques have further blurred the distinction between them.

Uneven-aged stands maintained by single-tree selection have been traditionally regulated by volume. According to Smith (1986), it might be more appropriately called regulation by diameter distribution or stand table. Although Smith states that "the volume method of regulation is really a sophisticated and indirect way of applying the area method", area control has not been used at the stand level. However, area control is used for regulating uneven-aged stands in a forest by guiding the amount of area that is to be scheduled for cutting each year or period (Davis and Johnson 1987). For example, a forest of 1,000 acres on a 5-year cutting cycle might have 200 acres scheduled for cutting each year.

The only long-term study of the group selection method that we could find was reported by Leak and Filip (1977). A 114-acre tract of New England hardwoods on the Bartlett Experimental Forest in New Hampshire was cut using group selection for 38 years on a 9-14 year cutting cycle starting in 1937; no cutting occurred between group openings. This cutting resulted in a reverse J-shaped stand structure typical of uneven-aged stands. Their conclusion was that group selection improves species composition by regenerating less shade-tolerant species and maintains stand conditions similar to those recommended for single-tree selection. They recommended that the group-selection method be used to provide for regeneration and the single-tree selection method to remove trees in the remainder of the stand. Leak and Filip expressed doubts that area regulation could be used because the groups were hard to identify after several years.

In a comprehensive discussion about group selection, Roach (1974) describes it only as a reproduction cutting method and not a silvicultural system. Roach asserts that regulating uneven-aged stands depends upon maintaining a balanced diameter distribution and that this distribution is achieved by controlling the density in three grouped basal area classes—such as pulpwood, small sawtimber, and large sawtimber. This is possible in stands under single-tree selection, because size classes are uniformly intermingled within the stand. But Roach maintains that group-selection cutting makes the stand more fragmented as more openings are created, then it becomes impossible to maintain a mental image of their dispersement throughout a stand. Thus, marking by size classes becomes difficult.

Roach concludes that there are only two ways to use group selection and maintain a sustained yield. One is to make groups very small so that stand variability is not increased and the stand can be regulated by stand structure. The other option is to make the openings large enough to use area control. If group selection is uncritically adopted, he warns that large fluctuations in yields will occur. If the requirement for sustained yield is relaxed, Roach relents and says that group selection might be used for aesthetic and environmentally sensitive areas and small private properties where there is not an overwhelming need or desire for sustained yield.

Other authors (Alexander and Edminster 1978; Gibbs 1978; Marquis 1978, 1989; Guldin et al. 1991) have echoed Roach's conclusion that stand structure control is the only regulation technique for uneven-aged silviculture. Foiles (1978), however, mentions the conversion of old-growth stands of ponderosa pine and Douglas-fir to uneven-aged ones by using a combination of both area and volume control. Boucher and Hall (1989) describe a procedure for implementing group selection in Appalachian hardwoods using economic guidelines.

Heald and Haight (1979) describe a procedure for managing naturally occurring vegetation groups in California's mixed conifer-oak stands. They classify these natural groups into six size classes (defined by tree diameter), regulate each group by basal area and spacing guides, and harvest and regenerate the groups when the general tree size exceeds a prescribed maximum diameter. A goal is to have these six size classes occupy approximately equal areas, but no attempt is made to keep track of group location.

Law and Lorimer (1989) describe a methodology for regulating uneven-aged stands of Central hardwoods. They use stand-structure regulation by specifying (1) a residual stand table; (2) a cutting cycle length; (3) opening sizes required by aspect and slope for successful oak regeneration; and (4) number of openings required by aspect, opening size, and residual stand table. The number of openings is based on the average area occupied by a 2-inch sapling at a B-stocking level (Ginrich 1967) and the number of trees in the 2-inch class for different stand structures. Thus, all the stand except for current group openings is regulated by a diameter distribution.

Marquis (1989) states that openings larger than 0.5 acres are difficult to regulate by volume or structural control. Thus for patch cutting, he recommends that the total area in new patches during each cutting cycle be based on the cutting cycle length and the length of an equivalent even-aged rotation. The residual stand would be tended by using thinning with no structural goal. Marquis (1989) concludes that this system will create uneven-aged conditions using even-aged techniques.

Critique

Group selection has some difficulties, especially as openings are created over several cutting cycles. As Roach (1974) stated, the stand becomes more heterogenous as more and more of the stand area becomes occupied with older group openings. After several cutting cycles, locating areas suitable for openings becomes more difficult. Unfortunately, our experience with the long-term consequences of group selection is virtually nil, except for the observations of Leak and Filip (1977). Therefore, many conclusions about stand irregularity and operational problems are speculative and hypothetical.

Roach's views (1974) had a strong impact on subsequent discussion of group selection, especially about sustained yield and regulation techniques. However, he did not discuss the impact of silvical requirements on opening size and how it must be incorporated into converting and regulating stands using group-selection cutting. An insistence that volume or stand-structure regulation is the only valid regulation method for uneven-aged stands appears to be unduly restrictive, and may be a consequence of the emphasis on stand-structure regulation with single-tree selection. However, area control may have a role in group selection.

Problems might arise when an exclusive reliance on stand-structure control is made in stands that have poor structure, such as mature sawtimber stands. Some guidance is needed to allocate the cut between the harvest cuts (the group openings) and stand tending (cutting in the residual stand for thinning, improvement, sanitation, etc). Otherwise, the total cut could be concentrated in openings at one extreme or in the residual stand itself at the other extreme with no openings being created. Law and Lorimer (1989) explicitly offer a solution to the problem of integrating group selection with stand regulation. They specify the number of group openings for Central hardwoods that might be made for a 15- to 20-year cutting cycle; openings represent about 3 to 9 percent of the total area. Although based on structure, any procedure that generates the number and size of openings is close to area control. Another approach would be to use area control directly.

Regulation Alternatives

How can a modification of area control be used for regulation and how can the opening size requirements of the species under management be integrated? Some guidelines can be adapted from even-aged management and follow Marquis' (1989) recommendations for patch cutting. We could assume that the harvested groups of mature trees would be approximately the same age as trees in an even-aged stand at rotation age, and this age would be the length of the conversion period required to fully regulate the stand. Opening size would depend upon the silvical requirements of the species and the stand height surrounding the opening. A cutting cycle length is chosen so that operable cuts can be made based upon the growth rates of trees in the stand and that suits the silvical requirements of the target species. The area in openings (OA) can be calculated from stand area (SA), conversion period (CP), and cutting cycle length (CC) by the following: OA = CC(SA/CP). The number of openings (N) is determined by dividing the area in openings by the average opening size (OS), or N = OA/OS. The advantages of this approach over Law and Lorimer's (1989) is that it is more direct, simpler to calculate, and is sensitive to the cutting cycle length. It seems appropriate that the acreage in openings should increase as cycle length is lengthened. Area regulation also seems to be appropriate for applications in even-aged stands that are being converted to uneven-aged ones. This is especially true during the early part of the conversion effort, when opening locations are easy to select. Regulation might switch to volume or structure later in the conversion period when multiple age classes exist.

The allocation of area to group openings just covers the reproduction method, and some consideration must be given to stand tending. Law and Lorimer's solution is to use stand structure for regulation, and their technique would seem to work well in stands where the smaller, subordinate trees are vigorous and the preferred species. However, if these subordinates are suppressed, poorly formed, or less preferred species, then their procedure would seem inappropriate. Such trees lower the quality of the residual stand, which violates a basic tenet of always improving stand quality. Figure 4 shows that most crop trees are in the larger diameters of a representative upland oak stand in the Boston Mountains of Arkansas. A strict application of structure control would leave the stand in poorer condition.

An alternative in such stands is to subject the residual stand to a free thinning to a prescribed basal area and rely on regeneration in openings to create uneven-aged structure. Although intriguing, this method, as with others, has not been tested in group selection. Unfortunately, the feasibility of any technique will have to be verified with long-term studies. Another approach might use computer simulation, but our present understanding of stand dynamics under these conditions is abysmal.

We are presently installing a study in upland oak stands in the Boston Mountains which tests these alternatives. We used two residual stand densities (65 and 85 ft^2 per acre) and two stand regulation procedures (free thinning versus structure control). The study includes two different aspects and is replicated three times. The whole study is composed of twenty-four 7.2-acre plots, in which detailed tree and reproduction measurements will be conducted. A group opening will be created on each plot every 10 years to mimic regulation on an operational scale. This study should provide a great deal of insight into how stands will respond to long-term group-selection cutting and provide answers about regulation strategy.

CONCLUSIONS

Group selection is a hybrid, blending elements of both even- and uneven-aged silvicultural systems. It seems particularly well suited for the middle ground, where administrative constraints preclude even-aged silviculture and restrict key elements of uneven-aged silviculture, such as periodic competition control, and it holds promise for regenerating the more shade-intolerant

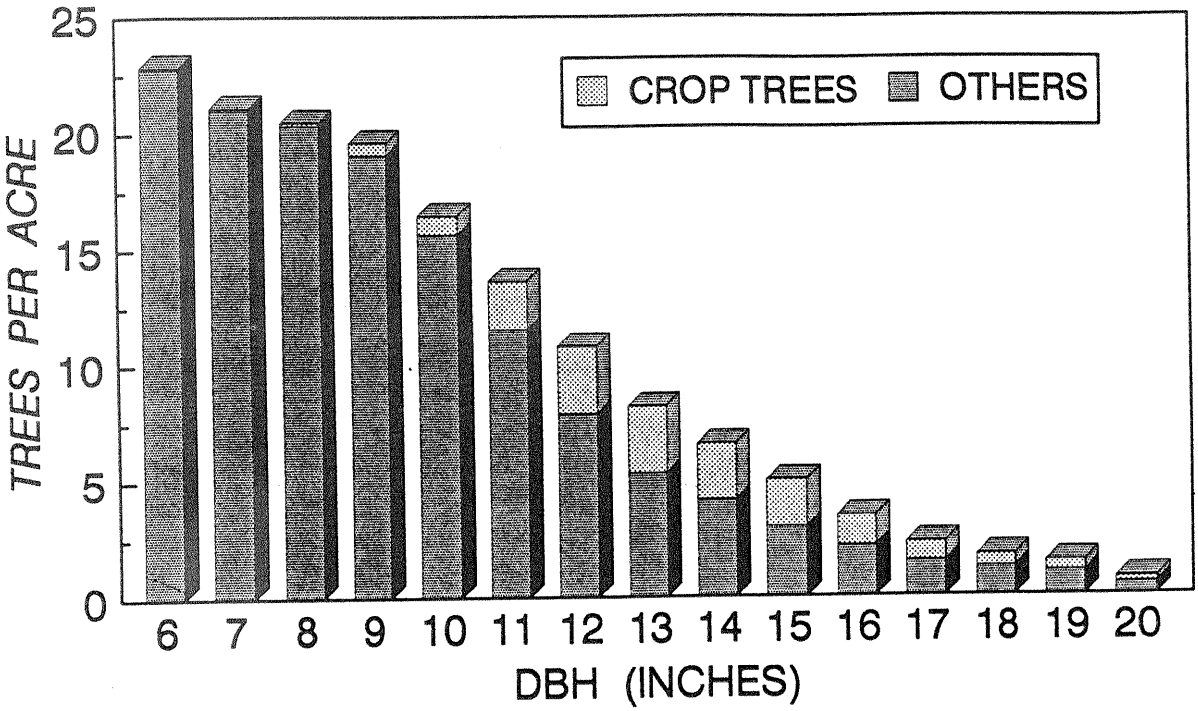

Figure 4.—Composite stand table of upland oaks by tree class in Boston Mountains of Arkansas (unpublished data, USDA Forest Service, Southern Forest Experiment Station, Monticello, AR).

species. Group selection will likely work best where natural regeneration is easily secured, landowners do not have a strong preference for species composition, and developing stands do not require much tending. Group selection is not without problems. The most pressing are (1) the inefficiency of applying silvicultural treatments to scattered openings and (2) stand variability--which increases the complexity of inventory, regulation, and prescriptions. Applications in oak stands are further complicated by the need to secure large advance regeneration.

Much of what has been written about group selection and feasible regulation alternatives is speculative (our paper included), because of the paucity of past research. A rejection of using area regulation seems to be due to the intimate association of volume or stand structure control with single-tree selection. However, this rejection does not seem to be justified, and using area control in conjunction with structure control for the residual stand appears to be a feasible alternative. We should also remind ourselves of the idea conveyed by Smith (1986) and Davis and Johnson (1987) that actual management does not depend upon strict dependence on classical regulation techniques. Incorporation of owner objectives and the use of modern management tools give foresters better, more flexible techniques to manage forests. As our understanding of group selection grows, we can also use these techniques for this much neglected cutting method.

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LITERATURE CITED

Alexander, R.R. and C.B. Edminster. 1978. Regulation and control under uneven-aged management. P. 217-230 in Combined proceedings on uneven-aged silvicultural in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Beck, D.E. 1970. Effect of competition on survival and height growth of red oak seedlings. USDA For. Serv. Res. Pap. SE-56.

Beck, D.E. 1990. Liriodendron tulipifera L. Yellow-poplar. P. 406-416. in Silvics of North America: Volume 2. Hardwoods. R.M. Burns and B.H. Honkala (tech. coords.). USDA Agric. Handb. 654.

Blair, R.M. and L.E. Brunett. 1976. Phytosociological changes after harvest in a southern pine ecosystem. Ecology 57:18-32.

Boucher, B.A. and O.F. Hall. 1989. Implementing group selection in Appalachian hardwoods using economic guidelines. P. 221-230 in Proceedings of the seventh central hardwood conference. G. Ring and C.A. Budelsky (eds.). USDA For. Serv. Gen. Tech. Rep. NC-132.

Bradshaw, F.J. 1992. Quantifying edge effect and patch size for multiple-use silviculture--a discussion paper. For. Eco. and Manage. 48: 249-264.

Carvell, K.L. 1979. Factors affecting the abundance, vigor, and growth response of understory oak seedlings. P. 23-26 in Regenerating oaks in upland hardwood forests; 1979 John S. Wright Forestry conference. H.A. Holt and B.C. Fischer (eds.). Purdue Res. Found., West Lafayette, IN.

Chapman, H.H. 1942. Management of loblolly pine in the pine-hardwood region in Arkansas and in Louisiana west of the Mississippi River. Yale Univ. Sch. For. Bull. 49:1-150.

Clark, F.B. and S.G. Boyce. 1964. Yellow-poplar seed remains viable in the forest litter. J. For. 62:564-567.

Davis, L.S. and K.N. Johnson. 1987. Forest management. 2nd ed. McGraw-Hill, Inc. New York.

Fischer, B.C. 1979. Managing light in the selection method. P. 43-53. in Regenerating oaks in upland hardwood forests; 1979 John S. Wright Forestry conference. H.A. Holt and B.C. Fischer (eds.). Purdue Res. Found., West Lafayette, IN.

Foiles, M.W. 1978. Stand structure. P. 176-185. in Combined proceedings on uneven-aged silviculture in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Franklin, Jerry F. 1978. Effects of uneven-aged management on species composition. in Combined proceedings on uneven-aged silviculture in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Gibbs, C.B. 1978. Uneven-aged silviculture and management? Definitions and differences. P. 18-24. in Combined proceedings on uneven-aged silviculture in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Ginrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. For. Sci. 13:38-53.

Guldin J.M. 1991. Uneven-aged BDq regulation of Sierra Nevada mixed conifers. J. For. 89:29-36.

Guldin, J.M., R.M. Farrar, Jr., J.D. Hodges, and J.R. Toliver. 1991. A subjective decision model for classification of uneven-aged silvicultural systems. P. 369-375. in Proceedings of the sixth biennial southern silvicultural research conference. S.S. Coleman and D.G. Neary (comps.). USDA For. Serv. Gen. Tech. Rep. SE-70.

Hannah, P.R. 1987. Regeneration methods for oaks. North. J. Appl. For. 4:97-101.

Heald, R.C. and R. Haight. 1979. A new approach to uneven-aged silviculture and management of mixed conifer-oak forests. California Agric. (May 1979):20-22.

Jackson, L.W.R. 1959. Relation of pine forest overstory opening diameter to growth of pine reproduction. Ecology 40:478-480.

Johnson, P.S. 1977. Predicting oak stump sprouting and sprout development in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-149.

Johnson, P.S. 1979. Shoot elongation of black oak and white oak sprouts. Can. J. For. Res. 9:489-494.

Johnson, P.S. 1984. Responses of planted northern red oak to three overstory treatments. Can. J. For. Res. 14:536-542.

Johnson, P.S., C.D. Dale, K.R. Davidson and J.R. Law. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. North. J. Appl. For. 3:66-68.

Kormanik, Paul P. 1990. Liquidambar styraciflua L. Sweetgum. P. 400-415 in Silvics of North America: Volume 2. Hardwoods. R.M. Burns and B.H. Honkala (tech. coords.) USDA Agric. Handb. 654.

Law, J.R. and C.G. Lorimer. 1989. Managing uneven-aged stands. P. 6.08(1)-6.08(6) in Central hardwood notes. F.B. Clark (ed.). USDA For. Serv. North Cen. For. Exp. Sta.

Leak, W.B. and S.M. Filip. 1977. Thirty-eight years of group selection in New England northern hardwoods. J. For. 75:641-643.

Loftis, D.L. 1990a. Predicting post-harvest performance of advance red oak reproduction in the southern Appalachians. For. Sci. 36:908-916.

Loftis, D.L. 1990b. A shelterwood method for regenerating red oak in the Southern Appalachians. For. Sci. 36:917-929.

MacKinney, A.L. 1934. Logging damage in selectively logged loblolly pine stands. J. For. 32:92-96.

Marquis, D.M. 1965. Controlling light in small clearcuttings. USDA For. Serv. Res. Pap. NE-39.

Marquis, D.M. 1978. Application of uneven-aged silviculture on public and private lands. P. 25-61 in Combined proceedings on uneven-aged silviculture in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Marquis, D.M. 1989. Alternative silvicultural systems-East. P. 36-45 in Proceedings of the national silviculture workshop: silvicultural challenges and opportunities in the 1990's. USDA For. Serv. Timber Manage.

Marquis, D.M. 1992. Accommodating biological and social issues in hardwood management: the northeast region. P. 111-125 in Proceedings: twentieth annual hardwood symposium of the Hardwood Research Council. National Hardwood Research Council, Memphis, TN.

McDonald, P.M. and G.O. Fiddler. 1991. Vegetation in group selection openings: ecology and manipulation. P. 97-106 in Twelfth annual forest vegetation management conference. Redding, CA.

McQuilkin, R.A. 1975. Growth of four types of white oak reproduction after clearcutting in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-116.

Minckler, L.S. 1986. My chance: who really understands group selection? J. For. 84: inside back cover.

Minckler, L.S. 1989. Intensive group selection silviculture in central hardwoods after 40 years. P. 35-39 in Proceedings of the seventh central hardwood conference. USDA For. Serv. Gen. Tech. Rep. NC-132.

Minckler, L.S. and J.D. Woerheide. 1965. Reproduction of hardwoods 10 years after cutting as affected by site and opening size. J. For. 63:103-107.

Nyland, R. D. 1987. Selection system and its application to uneven-aged northern hardwoods. P. 49-80 in Managing northern hardwoods; proceedings of a silvicultural proceedings. R. D. Nyland (ed.) Faculty For. Misc. Pub. No. 13. State Univ. of New York, Syracuse, NY.

Pomeroy, K.B. 1949. Loblolly pine seed trees: selection, fruitfulness, and mortality. USDA For. Serv., Southeast. For. Exp. Sta., Sta. Pap. 5.

Potter, M. J. 1988. Tree shelters improve survival and increase early growth. J. For. 86:39-41.

Roach, B.A. 1974. What is selection cutting and how do you make it work: what is group selection and where can it be used. State Univ. New York, AFRI Misc. Rep. No. 5.

Sander, I.L. 1971. Height growth of new oak sprouts depends on size of advance reproduction. J. For. 69:809-811.

Sander, I.L. 1972. Size of oak advance reproduction: key to growth following harvest cutting. USDA For. Serv. Res. Pap. NC-79.

Sander, I.L. 1987. Oak reproduction establishment and early development following shelterwood cutting in Missouri. P. 17-30 in Proceedings fifteenth annual hardwood symposium. Hardwood Res. Council. Memphis, TN.

Sander, I.L. 1988. Guidelines for regenerating Appalachian oak stands. P. 180-198 in Proceedings guidelines for regenerating Appalachian hardwood stands. H.C. Smith, H.C. Perkey, and W.E. Kidd, Jr. (eds.). SAF Publication 88-03. Virginia Univ. Books. Morgantown, WV.

Sander, I.L. and F.B. Clark. 1971. Reproduction of the upland hardwood forests in the Central States. USDA Agric. Handb. 405.

Sander, I.L., C.E. McGee, K.G. Day, and R.E. Willard. 1983. Oak-hickory. P. 116-120 in Silvicultural systems for the major forest types of the United States. R.M. Burns (tech. comp.) Agric. Handb. 445.

Sander, I.L., P.S. Johnson, and R. Rogers. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-251.

Smith, H.C. 1980. An evaluation of four uneven-age cutting practices in Central Appalachian hardwoods. So. J. Appl. For. 4:193-200.

Smith, H.C. 1981. Diameters of clearcut openings influence Appalachian hardwood stem development--a 10-year study. USDA For. Serv. Res. Pap. NE-476. Smith, D.M. 1986. The practice of silviculture. John Wiley and Sons. New York.

Waldrop, T.A. 1991. Pine-hardwood regeneration in small openings for uneven-aged management. P. 398-408 in Proceedings of the sixth biennial southern silvicultural research conference; S.S. Coleman and D.G. Neary (comps.). USDA For. Serv. Gen. Tech. Rep. SE-70.

Wahlenberg, W.G. 1960. Loblolly pine. Duke Univ. Durham, NC.