PAST AND PRESENT SILVICULTURE AND HARVESTING PRACTICES IN CENTRAL AND NORTHERN HARDWOODS

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Abstract -- Northern hardwoods can be managed by either even- or uneven-aged systems, and successfully regenerated if deer browsing and undesirable understory vegetation do not interfere with the seedlings. Oak (Quercus sp.) stands are essentially even-aged, and cannot be easily regenerated unless they contain abundant and well-spaced tall advance saplings. Methods to promote height growth of understory oaks have not been perfected. Most sawtimber stands of both type groups are commonly cut to remove high value and large-diameter trees. Diameter-limit cuttings in second-growth stands purge these communities of the fastest growing trees and the shade-intolerant species. Such practices will not improve the genetic quality of subsequent stands, and may prove disgenic. Deliberate silviculture offers the potential for at least base-level genetic improvement over the long run.

THE EASTERN HARDWOOD FOREST, ITS USE, AND CHARACTER

Various northern hardwood- and oak-dominated communities cover over 141 million ac in northeastern United States (Nyland et al. 1981, Sander et al. 1981). Sugar maple (Acer saccharum Marsh.)-dominated northern hardwoods extend from the Atlantic coast to Minnesota, and from the boreal forests of eastern Canada southward through high elevations of the Appalachians, and into Missouri. Oak types extend south of the northern hardwoods from New England to the Lake States, occur westward to the prairie, and southward to the Gulf. These forests yield products to serve diverse human needs, serve as important watersheds, and provide habitat for a variety of wild creatures. In addition, they satisfy many top-commodity interests in and around urban centers, and at more remote locations.

Silvicultural practices vary somewhat from stand to stand to accommodate characteristics of the different species present. To capitalize upon the more lucrative sawtimber and veneer markets, landowners must concentrate the growth potential on trees having well-defined phenotypic characteristics, and a high potential for rapid growth. We can satisfy most other uses by maintaining the species diversity or limiting it, by developing a particular mix of stand conditions, and/or by insuring long-term continuity of forest cover across the landscape.

The vast quantities of fiber currently available at low cost, and the continuing increase for both volumes of and area in eastern hardwoods, make programs to improve fiber yield unlikely. Forest tree improvement concerns have relevance only for high-value solid wood products from choice species, and for some special urban tree needs. We look to forest tree improvement specialists primarily to concentrate on the form, height development, natural pruning, and growth rate of selected species that command high prices in specialty markets.

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These Include black cherry (_Prunus serotina_ Ehrh.), white ash (_Fraxinus americana_ L.), black walnut (Juglans _nigra_ L.), red oak (Q. _rubra_ L.), and white oak (Q. _alba_ L.).

NORTHERN HARDWOODS

Both even- and uneven-aged silvicultural systems work effectively for northern hardwoods. Research has also provided managers with the tools to address many different management objectives from one stand to another, and between ownerships.

Uneven-aged Management

Selection system cuttings control the density within different size classes to influence the uniformity of production over successive cutting cycles, the patterns of regeneration across the stand, and the quality and value of growing stock. In marking, the forester removes excess trees to maintain a specified residual number per size class, and harvests financially mature trees to regenerate a fixed proportion of the stand area once each cutting cycle. These treatments also improve the quality of the growing stock, and reduce crowding among the immature classes. Failure to deliberately attend to all of these components (regeneration, tending, and harvest) makes the result unpredictable, and the yields irregular (Nyland 1987).

Residual stand conditions -- Work by Eyre and Zillgitt (1953) and Gilbert and Jensen (1958) led to guidelines by Arbogast (1957) and Leak et al. (1969) for selection system based upon a 8-12 yr cutting cycle. More recently, Hansen and Nyland (1986) and Nyland (1987) presented alternative structures for longer cutting cycles, different stand conditions, and various landowner objectives as follows:

	Arbogast guide	Alternate residual stocking for cutting cycle of different lengths			
Diameter class	8-12 yrs Sq ft/ac	15 yrs Sq ft/ac	20 yrs Sq ft/ac	25 yrs Sq ft/ac	30 yrs Sq ft/ac
2-5	10	10	10	10	10
6-11	20	25	20	30	25
12-17	30	35	30	25	20
18+	30	15	10	-	-
Total	90	85	70	65	55

Trimble et al. (1974) proposed a flexible maximum diameter of 18-22 in, leaving larger trees on the better sites and among the faster growing and more valuable species. Hansen (1987) found no reason to retain ones greater than 20 in dbh when using a 15-yr cutting cycle to maximize large sawtimber (>18 in dbh) volume and value growth. To maximize return on investment (compound interest) he recommended a 25-yr cutting cycle, a maximum residual dbh of 16 in, and density of 55-60 sq ft/ac.

Crow et al. (1981), Mader and Nyland (1984), and Nyland (1986b) attest to the validity of the residual structure by Arbogast (1957) and Leak et al. (1969). Recent computer simulation work by Davis (1988) using the model developed by Hansen (1987) indicates that the diameter distribution of stands brought into close conformity with these structures remains stable over repeated cutting cycles, and adequate numbers of desirable trees develop from regeneration to fill the lower end of the distribution. For appropriately structured stands, growth and yield has generally averaged between 2.5 and 3.0 sq ft/ac/yr for basal area (Eyre and Zillgitt 1953, Marquis et al. 1954, Blum and Filip 1963,, Mader and Nyland 1984), and 200-300 bd ft/ac/yr (Eyre and Zillgitt 1953, Nyland and Mader 1984).

Nyland and Gabriel (1971) and Nyland et al. (1976) reported substantial numbers of injuries among partially cut uneven-aged stands. These included broken branches, basal injuries, and even damages that destroyed some trees. Trees with major injuries comprised about one-fifth of the residual basal area, and numbers of injuries per age class were related to the numbers of residual trees/ac of that size. They found little opportunity to reduce the frequency of injury, and suggested that repeated partial cutting might maintain a base level of physical defect in the stand.

<u>Regeneration</u> --Shade-tolerant species regenerate in abundance following almost any type of partial cutting, given an adequate source of viable seed and no adverse environmental conditions (Eyre and Zillgitt 1953, Marquis et al. 1954, Wallenberg 1956, Gilbert and Jensen 1958, Trimble and Hart 1961, Barrett et al. 1962, Blum and Filip 1963, Trimble 1973, Tubbs 1977a, Crow et al. 1981, Crow and Metzger 1987). Most uneven-aged stands have advance regeneration of shade-tolerant species, and these seedlings and small saplings grow upon release to become the new age class (Trimble 1961, Leak and Wilson 1968, Tubbs 1968, Mader and Nyland 1984). Intensive deer browsing can preclude success, as with any reproduction method.

While the composition of the new age class usually reflects that of the advance regeneration (Blum and Filip 1963, Leak and Wilson 1968), heavy cutting that leaves a low density residual stand (Sander and Williamson 1957, Blum and Filip 1963, Trimble and Hart 1961, Trimble 1973, Crow and Metzger 1987), or cutting of groups or patches (Eyre and Zillgitt 1953, Trimble and Findley 1963, Leak and Filip 1977, Tubbs 1977a, Crow and Metzger 1987) will increase the representation of the less shade tolerant species. Generally, the openings should cover at least one-tenth to one-fifth ac.

Published findings do not highlight negative effects of interfering understory vegetation by shrubs or undesirable tree species in uneven-aged stands. Yet Marquis et al. (1984) and Marquis (1987) include these plants in their regeneration assessment method. Richards and Farnsworth (1971) did find that beech dominated the regeneration following partial cuts of different intensities in stands where deer browsing was intense and beech had formed a dense understory prior to cutting. Striped maple may also proliferate following cutting in some stands.

<u>Converting Second-growth Stands</u>

Some landowners decide to convert existing even-aged (second-growth) stands to a two-age condition, with a goal of practicing uneven-aged management over the long run. For these cases, Erdmann (1987) recommends selecting 50-55/ac of high quality trees in upper canopy positions (dominant and codominant), releasing their crowns by 7 ft on all sides, removing any sub-canopy trees below these crop trees, and thinning the remainder of the stand from below to the minimum level recommended on the stocking chart by Tubbs (1977b). He also suggests creating five to eight 25-40 ft openings/ac each cutting cycle. After three of these treatments the stand should have an uneven-aged structure, likely dominated by shade-tolerant species.

Even-aged Management

No forester ever sees an even-aged stand through an entire sawlog rotation. We regenerate some financially mature stands, and thin many immature ones. But unlike uneven-aged systems, the treatments to regenerate a new age class and tend older ones never occur simultaneously. As a result, we often envision even-aged management as more simple. We often treat conditions we find at a given time, rather than to plan the coordinated management for an entire rotation.

Early treatments -- Most landowners do not consider pre-commercial treatment of northern hardwoods economically attractive. Also, cuttings at the sapling or early pole stages may result in sunscald, epicormic branching, delayed natural pruning, and resultant low forking (Conover and Ralston 1959, Blum 1963, Godman 1968). Where pre-commercial treatments appear desirable, Smith and Lamson (1987) recommend chainsaw felling of all trees that interfere with the crowns of 50-75 selected crop trees/ac. These should have 25-30 ft of high quality and straight bole, and occupy dominant or codominant positions. For pole stands, Erdmann (1987) recommends releasing about 75 crop trees/ac by 7 ft on all sides, and also cutting sub-canopy trees within this distance.

Thinning -- The relative density guides by Leak et al. (1969), Roach (1977), Tubbs (1977b), and Marquis et al. (1984) use numbers of trees, their sizes, and the basal area to describe unthinned stands at different stages of development (100% relative density). They also recommend a minimum residual for thinning. Roach (1977), Tubbs (1977b), and Marquis et al (1984) also showed that these levels vary with differences in species composition, both for thinned and unthinned stands.

The guides by Roach (1977) and Marquis et al. (1984) recommend thinning to a residual relative density of 60%. This threshold should provide full net annual cubic-foot production over a thinning cycle (Ernst 1987, Marquis 1986). It maintains sufficient stocking to inhibit epicormic branching on the residual trees, and promotes low pruning due to inter-tree shading (Marquis 1986, Marquis et al. 1984). They recommend thinning again when the stand regrows to 80% relative density. Mortality increases at higher levels of stocking, and cutting from 80% to 60% will usually provide sufficient volume for a commercial operation in stands past 50-60 yrs of age (Marquis 1986, Stout 1987).

Roach (1977) and Marquis et al. (1984) also include a procedure for developing a stand treatment prescription with an implicit method of thinning that takes about two-thirds of the basal area from below the mean stand diameter, and the remainder from larger trees. My own studies indicate that many 60-80 yr old unthinned stands at northern latitudes have defective and high risk trees throughout the diameter distribution, and that to salvage the volume some cut must be made across the diameter classes.

Selection thinning (taking out the largest trees in a diameter-limit type of cut) will remove the best volume-producing trees and reduce subsequent sawtimber yields. By contrast, Marquis (1986) suggests that thinning from below or crown thinning will insure the highest levels of volume growth. Similarly, Solomon's (1977) simulation work indicated that best board-foot growth will come from stands thinned according to available stocking guides, and leaving about 60% of the residual basal area in sawtimber-sized trees. Such thinnings increase the board-foot yields by 50-100% over rotations of 90-125 years (Solomon and Leak 1986). One-third to one-half of the yield will come from removals during the thinning operations. By favoring trees of good phenotypic character the thinnings also enhance stand quality. Nyland (1986a) has observed that thinnings to favor trees of upper crown positions should not result in extensive logging damage if the contractor carefully controls the skidding process and uses machinery matched to the site, the timber, and the method of thinning.

Regeneration -- Both clearcutting and shelterwood methods have proven effective in regenerating new even-aged crops of northern hardwoods. Generally, the new crop emanates from advance seedlings and small saplings (Jensen 1943, Wendel and Trimble 1968, Grisez and Peace 1975, Marquis et al. 1954, Tubbs 1977a). Consequently, Tubbs (1977a) recommended leaving some overstory in place until the understory has at least 5000/ac of desirable species at least 3 ft tall. In such stands complete overstory removal is appropriate (Marquis 1967, 1987; Roberge 1977; Walters and Nyland 1988).

For stands with inadequate advance regeneration, managers should use the shelterwood method. A variety of residual stocking levels appear appropriate, ranging from 50 sq ft/ac or less (Curtis and Rushmore 1958, Richards and Farnsworth 1971, Leak and Solomon 1975, Kelty and Nyland 1981), to as much as 90 sq ft/ac (Metzger and Tubbs 1971). Kelty (1987) observed that a range of 30-80 sq ft/ac will give acceptable stocking of desirable species, although seedlings grow best at 30-40 sq ft/ac. Tubbs (1977b) recommended leaving 60% crown cover in the upper Lake States in order to limit the development of shrubs and herbaceous plants. Also, Marquis (1978) reported better results by removing one-third rather than two-thirds of the basal area from cherry-maple stands on the Allegheny Plateau of Pennsylvania. Leak (1963) recommended taking 20% rather than 40% of the basal area in New England. In all regions, the lapse time until the removal cutting will be shorter when the seed cutting leaves a high density shelter.

For both clearcutting and shelterwood methods, the make-up of advance regeneration does not dictate the final species mixture. Pre- and post-cutting composition may differ. For example, Marquis (1967) found that even when shade-tolerant species dominated the advance regeneration, shade intolerant ones might comprise three-fourths of the basal area after 25 yrs. Jensen (1943), Nyland and Irish (1971), Wendel and Trimble (1968), and Metzger and Tubbs (1971) reported similar responses, though not necessarily of the same magnitude. Lees (1987) also noted that compared to other methods, clearcutting will generally produce a higher proportion of shade intolerant species and sprouts. The new germinants come from seed stored in the litter, plus that falling from light-seeded species into the regeneration area after cutting.

Rubus will develop across the site following cuttings of at least one-half of the basal area, or clearcutting. That poses no problems in eastern regions, where the tree regeneration emerges from the berry bushes by the 6th or 7th year (Kelty and Nyland 1981, Kelty 1987, Walters and Nyland 1988). In the upper Lake States, the proliferation of Rubus and herbaceous plants following heavy cutting may delay successful development of the tree regeneration (Metzger and Tubbs 1971, Tubbs 1977a). As a result, shelterwood method is preferred in the region.

Lees (1987) points out that complete overstory removal on some sites may lead to drying of the soil and surface organic material to the detriment of seedling survival. Further, dispersal of heavy-seeded species will be limited to margins of the clearcut. Strip and patch clearcutting provide alternatives for addressing these shortcomings. Patch size, strip width, and the orientation of either can be regulated to control shading patterns and seed dispersal (Marquis 1965a, 1965b; Lees 1987).

Interfering vegetation has proven a problem in successfully regenerating new even-aged crops in many areas. These include ferns and grasses (Tubbs 1973, Marquis 1987), or a dense beech understory (Kelty and Nyland 1981, Marquis 1987). Marquis et al. (1984) and Marquis (1987) describe a method for assessing the importance of these plants and judging the need for pre-cutting site preparation to reduce their numbers. Assessments following a wide range of cuttings in stands with dense beech understories have shown that failure to apply adequate control measures will lead to the domination by beech in the new crop (Richards and Farnsworth 1971, Kelty and Nyland 1981). By contrast, the shelterwood method yielded adequate numbers of desirable species in similar stands when preceded by site preparation to reduce the beech understory (Kelty and Nyland 1981, Kelty 1987). When present across large stands, these understories are most efficiently controlled using herbicides applied with a skidder-mounted mist blower (Sage 1987).

CENTRAL HARDWOODS

Oak types occur over a range of site conditions. They often contain an array of species, including ones of other genera. Further, oaks grow slowly under shading, and mostly occur in even-aged stands. Single-tree selection system will not perpetuate the oaks, and to work effectively the group selection method must open areas comparable to small clearcuts (Watt et al. 1979, Sander et al. 1981). Essentially, even-aged silvicultural systems must be used to reproduce stands containing a high proportion of oaks.

Regeneration Requirements

Oaks have historically proven difficult to regenerate (Clark and Watt 1971). On the drier and harsher sites where other species fail to develop adequately the oaks often succeed (Carvell and Tryon 1961, Clark and Watt 1971, Curtis 1959, Weitzman and Trimble 1957). But in moister and cooler environments other non-oak trees and woody shrubs tend to form dense understories, and may eventually dominate the stand following cutting (Anderson and Adams 1978, Arend and Gysel 1952, Cottam 1949). Normally it takes well established advance oak seedlings well distributed across the site to maintain a good representation of oaks following any reproduction method (Sander and Clark 1971, Sander 1972).

The amount of oak in a new stand is directly related to the amount of tall advance oak reproduction present prior to harvest (Arend and Scholz 1969, Carvell and Tryon 1961, Johnson and Jacobs 1980, Sander 1971). Many mature oak-hardwood stands have sparse (Carvell and Tryon 1961, Merritt 1979), or abundant but short oak advance regeneration (Carvell and Tryon 1961, Tryon and Carvell 1958). Under these conditions, regeneration efforts fail (McGee 1975), because oak advance regeneration shorter than 4.5 ft does not grow as rapidly as competing vegetation upon release from overstory shading (Clark and Watt 1971; Sander 1971, 1972).

With the oak types, regeneration develops through a long, gradual process (Sander and Clark 1971), perhaps beginning 20 yrs or more before the end of a rotation (Sander et al. 1981). Available guidelines call for a minimum of 433/ac of advance saplings at least 4.5 ft tall prior to overstory removal (Sander et al. 1976, 1984). Some supplemental stocking will come from stump sprouts (Johnson 1977, Sander et al. 1984), but these alone will not suffice in maintaining a high proportion of oak in the new age class.

Tryon and Carvell (1958), Arend and Scholz (1969), Sander and Clark (1971), and Graney and Rogerson (1985) suggested using shelterwood method to encourage development of the small oaks into larger sizes. Yet these and other reports lack clear examples where this technique has worked consistently. However, McGee and Bivens (1984) have demonstrated that releasing over-topped pole-size white oak will stimulate their development into crop trees. Apparently, where forest managers do find the tall oaks well distributed in the stand understory these trees succeed upon release, even if quite old.

Group or patch cutting has been used to regenerate oaks, but these succeed mainly when the area beneath the patch has tall advance oak regeneration. The patches should cover at least 0.5-1.0 ac in order to provide adequate light for long-term sapling growth throughout most of the patch area (Watt et al. 1979, Smith 1981). Due to their size, after a couple of cuttings these small even-aged mini-stands cover a large proportion of the total stand area, making conditions fairly even-aged throughout.

Site Preparation

Future efforts to regenerate oaks should likely include a combination of site preparation to reduce competition by undesirable non-oak species, and shelterwood method (Nyland et al. 1983, Graney and Rogerson 1985). This program may need to begin even in the 5th or 6th decade of a sawlog rotation. It will likely require a series of stand density control treatments, coupled with good seed years. For the present, research has focused upon reducing the density and size of competing trees and woody shrubs that commonly develop in the understory of oak-dominated stands.

Many silviculturists have proposed using prescribed fire to reduce understory interference of oak advance regeneration (Curtis 1959, Clark and Watt 1971, Huntley and McGee 1982, Johnson 1974, McQuilkin 1979, Merritt 1979, Roach 1971). On the surface, prescribed burning has considerable appeal as a site preparation method. Fire was common during the period when many existing sawtimber-status oak regenerated. Further, the oaks have several adaptations that make them resistant to fire, and oak seedlings and saplings resprout and grow rapidly when killed back to the ground line. In collection, these features make the oaks appear ideally suited to withstand repeated prescribed burning.

Despite numerous experiments at many locations through the central hardwood region, and in the transition zone north and east of it, prescribed burning has not proven effective (e.g, Wendel and Smith 1986). Responses look impressive during the first few years following a burn, but gradually non-oak species redevelop to overtop the oaks. Additional experience is needed with using prescribed burning as a site preparation tool (Clark and Watt 1971, Johnson 1984, Loomis 1981, McQuilkin 1979, Merritt 1979).

Application of herbicides might provide one alternative to prescribed buying, but understory spraying using mistblowers will kill all the understory vegetation in oak stands, similar to results reported by Sage (1987). This includes any advance oak regeneration. As a result, mistblowing in oak stands would necessarily initiate a long process of establishing new oak seedlings, as well as promoting their growth to acceptable sizes before overstory removal. Alternatively, you could protect individual oak seedlings with covers, or treat individual no-oak trees and shrubs. However, such practices appear commercially impractical.

Thinning

Experience indicates that early stand treatments will promote oak development in established stands, and shorten the time to grow trees to sawtimber sizes (Gingrich 1971, Dale and Hilt 1986). Financial advantages have not been adequately documented. Also, heavy thinning at early ages may adversely effect tree quality (Dale 1972, Dale and Sonderman 1984). But for cases where early pre-commercial thinning appears desirable, Smith and Lamson (1986) recommend low thinnings that remove one-third to one-half of the basal area from sapling stands, or alternatively cutting all trees that touch the crowns of 50-75 crop trees/ac once the codominants reach 25 ft tall. Subsequent thinnings should maintain the residual stocking at higher levels (Dale and Hilt 1986).

Thinnings in older oak-dominated stands should maintain most of the stocking in dominant and codominant oaks. This means selecting residual trees from among the upper half of the diameter range present, favoring trees of good quality, and striving for uniform spacing of the residuals (Roach and Gingrich 1968). The diameter growth of young oaks will increase almost immediately following such release (Gingrich 1971), but for older trees the radial increment will increase only gradually following thinning (Carvell 1971, Dierauf 1986), or not at all (Gingrich 1971). Individual tree growth is related to crown development (Gingrich 1971, Dierauf 1986), and repeated thinning is needed to maintain increased levels of individual-tree increment (Dierauf 1986). Stand-wide yield improvement may be small following about three-fourths of a rotation (Roach and Gingrich 1968). By favoring oaks and cutting trees of other species, thinnings help to decrease the seed source of non-oak species.

Roach and Gingrich (1968) developed stocking guides based upon the numbers of trees and stand basal area/ac, and recommended a minimum of just under 60% relative density for residual stands following thinning (Gingrich 1971). This level provides for full site utilization, and no reduction of tree quality. Dale (1972) observed that maximum total cubic-foot volume growth occurs between 30 and 60% relative density, depending upon the ingrowth from saplings. However, Sondermann (1984) and Dale and Sondermann (1984) also noted a decline among several tree quality indices where thinning reduced the basal area by one-half or more. Also, the low stocking creates favorable conditions for understory development (Roach and Gingrich 1968), as do diameter-limit cuttings and thinning methods that remove trees of the upper crown positions (Kirkham and Carvell 1980).

Dale (1968, 1972) and Roach and Gingrich (1968) recommend reducing the relative density in a first thinning by only 30-35% to safeguard residual tree quality. Subsequent thinnings may drop it to 50-55%. The thinning regime should maintain at least 50% relative density in order to fully occupy the site with potential crop trees (Dale 1972). Basal area growth may range from as high as 4 ft sq/ac/yr among thinned young stands, to as little as 1 ft sq/ac/yr for ones older than 70 yrs. For thinned stands, more than 50% of the total cordwood and sawtimber yield may be recovered during the intermediate treatments (Gingrich 1971) For appropriately managed stands the rotation may be reduced by 30-50% (Beck 1986). Even so, sawtimber rotations will span 100-120 yrs, depending upon site quality (Dale and Hilt 1986).

CURRENT PRACTICE

Johnson and Overton (1984) and Maynard et al. (1987) argue that practicing foresters, and landowners, can exert considerable influence over the genetic character of natural stands through deliberate tree marking and a well-planned reproduction method. The gains will be modest from these "base level" efforts, but better than high-grading the growing stock generation after generation.

Deliberate silviculture controls the growth, composition, and character of forest stands. Each treatment also improves the quality of the growing stock by concentrating the growth on the best trees, or by leaving ones of desired species and good phenotypic character as the seed source for the reproduction method. Thereby, deliberate silviculture will maintain or improve the genetic constitution of the growing stock, at least to the degree that it is manifest through the phenotypic character of the trees.

Exploitation Cutting

The widespread practice of extracting products rather than deliberately managing hardwood stands may have negative genetic effects. It is "selective cutting", defined by the Society of American Foresters (Ford-Robertson 1971) as:

> "...creaming, culling, high grading...A type of exploitation cutting that removes only certain species... above a certain size... of high value, known silvicultural requirements and/or sustained yields being wholly or largely ignored..."

Maynard et al. (1987) equate this with "...destroying the first, second, and third place finishers in every horse race, and putting the last place finishers out to stud."

While "high-grading" fits within this context, not all selective cuttings will be disgenic. Technically, improvement cuttings are selective cuttings because they serve only to free better quality trees by removing adjacent poor ones, and do not necessarily regulate residual relative density or spacing. They are not disgenic. A selective cutting may also simply purge some choice species from a stand, and coincidentally release advance regeneration derived from the entire gene pool prior to the harvest. Even so, most selective cuttings will probably not improve of the genetic character of the growing stock, and may entail the loss of a species from a stand.

The availability (or lack) of markets for low value and small diameter trees largely dictates the approaches that landowners take in managing northern and central hardwood stands. They have no difficulty selling large-diameter logs of good quality. At localities with outlets for fiber products (e.g., pulpwood and firewood) they also can profitably cut among the smaller diameter classes and in younger stands as a commercial venture. Otherwise, the landowner must usually invest in cull removal and small-tree tending, and most have historically opted not to spend the money.

Under poor market conditions, uneven-aged management amounts to manipulating only the sawtimber classes, or diameter-limit cutting. For even-aged stands the economic constraints force a delay of the first thinning until the stand will sustain a commercial operation, encourage cutting only among the merchantable size trees, or promote diameter-limit removals of the sawtimber from immature stands.

Even-aged Stands

Throughout the northern hardwood region, some kind of acceptable regeneration is relatively easy to secure, except in areas of intense deer browsing or with dense understories of interfering vegetation. The choice between clearcutting and shelterwood methods depends upon the amount and status of the advance regeneration. For central hardwoods, forest managers currently lack fail-safe methods to successfully regenerate the oaks following any reproduction method, particularly on the more mesic sites and for stands lacking tall advance oak saplings. For oak stands where landowners elect to terminate the rotation, they must accept a shift of species composition within the new crop.

Once established, the less shade tolerant species grow fastest, both with northern and central hardwoods, and most of them also have the highest individual tree value. By 70 yrs of age, the larger stems will have reached small-sawtimber sizes. Ideally, the forest manager would thin to favor these vigorous trees of upper crown positions (and largest diameters) to encourage their growth into large-sawtimber sizes over a shortened rotation. Instead, many landowners have begun to cut the largest, fastest growing, and most vigorous trees. Smaller ones of the same age, mostly shade tolerant, are left for future growth despite their poor vigor and irregular stocking. Such a practice is disgenic. Also, by taking out most of the shade-intolerant trees these cuttings remove an important seed source for the future. The long-term consequence may prove substantial.

Diameter-limit "thinnings" also tend to leave low residual stocking, and this triggers premature regeneration among stands 70 or more yrs old, at least in eastern portions of the region. Shade-intolerant seedlings will stay alive for several years. But by the end of a 10-15 yr period the crown canopy closes sufficiently to darken the understory, and the shade-intolerant species lose vigor and decline. Shade tolerant ones continue to grow slowly, and repeated cuttings at 10-15 yr intervals promote their development until a dense second canopy forms beneath the overstory trees. This understory will likely hamper opportunities to regenerate a shade-intolerant component in the next crop (e.g, oaks, black cherry, or white ash), unless the landowner does site preparation to reduce the understory and make conditions more favorable to shade-intolerant species.

Sawtimber Stands

Sawtimber-class stands of northern and central hardwoods have not escaped indiscriminate cutting. Uneven-aged "management" has historically meant extracting merchantable timber, rather than applying selection system. Selective cuts include out-right high-grading, diameter-limit cutting, improvement cutting among saleable size classes, species removals, and efforts to manipulate the sawtimber sizes while bypassing the smaller trees. All result in an uneven-aged stand of irregular character.

Among partially cut stands, the openings fill with some mixture of trees and/or shrubs following relatively brief periods of time. Deer browsing or interfering plants may adversely affect species composition of the regeneration, but cuttings in many northern hardwood stands result in a complement of acceptable species. For central hardwoods, this "management" regenerates non-oak trees (including acceptable species) and shrubs. For both type groups, the proportion of shade tolerant species increases, especially in heavily stocked portions of the stand. However, given a seed source, ones of low shade tolerance will develop underneath sizable canopy openings.

Most residual stands conform to no particular structural goal. The range of diameters becomes more narrow with each subsequent entry, particularly in areas with poor market for small trees. My own research, like earlier conclusions by Roach (1974), indicates that following two or three sawtimber-only removals the proportion of poles will increase, crowding will develop among the small trees, regeneration may become sparse or spatially discontinuous, and yields will decline. The stands will eventually develop a narrow range of diameters, and cannot be perpetuated as uneven-aged.

CONCLUSIONS

The potential for widespread improvement in current cutting practices depends upon better markets for low quality and small diameter trees. Then landowners could economically perform early thinnings, treat the pole classes in uneven-aged management, and cut small trees in a variety of intermediate treatments. We do have many examples of these improved practices where suitable markets exist, and advances through research continue to provide these landowners with even better opportunities for the future. However, I expect limited expansion of the fiber markets, and sense that selective cutting will become more widespread. As a result I foresee that we stand today at the threshold to the second great exploitation of the eastern hardwood forest.

This prognosis implies both economic and genetic effects. First, diameter-limit cutting among second-growth forests will purge many stands of the high-value species and the best-growing genotypes. Value and volume growth will decline throughout the remainder of the rotation, and the owner will lack an adequate seed source to maintain a high proportion of some shade intolerant species into the next rotation. Hence, we may see lesser amounts of species like the oaks and black cherry.

Selective cutting also leaves the phenotypic "runts" as a seed source. For species like sugar maple that occur as advance regeneration underneath many stands, the selective cuts likely have limited negative genetic effects. But for species that do not occur abundantly as advance regeneration, the seed will come from residual trees that never grew well and have a poor phenotypic character in other respects. This may prove disgenic over the long run.

I see northeastern hardwood "management" an important juncture. Unless we find better ways to promote deliberate silviculture, we may be headed back along the road of history, repeating the practices of past decades across millions of acres of land that are being cut rather than managed. I cannot predict what events may influence landowner decisions. I just recognize that the current course will lead us backward, even at a time in history when we have the technology and understanding to improve our practices, and to bring the northern and central hardwood forests under more effective long-term management.

LITERATURE CITED

Anderson, R.C. and D.E. Adams. 1978. Species replacement patterns in central Illinois white oak forests. In: P.E. Pope, ed. Cent. Hwd. For. Conf. II, Nov. 14-16, 1978, Purdue Univ., W. Lafayette, IN.

Arend, J.L. and L.W. Gysel. 1952. Less oak reproduction on better sites. US. For. Serv., Lake States For. Exp. Stn. Tech. Note 578.

Arend, J.L. and H. F. Scholz. 1969. Oak forests of the Lake States and their management. US For. Serv. Res. Pap. NC-31.

Arbogast, C., Jr. 1957. Marking guides for northern hardwoods under the selection system. US For. Serv., Lake States For. Exp. Stn., Stn, Pap. 56.

Barrett, J.W., C.E. Farnsworth, and W. Rutherford Jr. 1962. Logging effects on regeneration and certain aspects of microclimate in northern hardwoods. J. For. 60:630-639.

Beck, D.E. 1986. Thinning Appalachian pole and small sawtimber stands. In: H.C. Smith and M.C. Eye, ed. Guidelines for Managing Immature Appalachian

Hardwood Stands. Proc. Workshop, 28-39 May 1986, W.Va. Univ., Morgantown, WV.

Blum, B.M. 1963. Excessive exposure stimulates epicormic branching in young northern hardwoods. US For. Serv. Res. Note NE-9.

Blum, B.M. and S.M. Filip. 1963. A demonstration of four intensities of management in northern hardwoods. US For. Serv. Res. Pap. NE-4.

Carvell, K.L. 1971. Silvicultural aspects of intermediate cuttings. In: D. E. White and B.A. Roach, Ed. Oak Symposium Proceedings. US For.Serv. Northeast. For. Exp. Stn., Upper Darby, PA.

Carvell, K.L. and E.H. Tryon. 1961. The effect of environmental factors on the abundance of oak regeneration beneath mature oak stands. For. Sci. 7:98-105.

Clark, F.B. and R.F. Watt. 1971. Silvicultural methods for regenerating oaks. In: D.E. White and B.A. Roach, ed. Oak Symposium Proceedings. US For. Serv., Northeast. For. Exp. Stn., Upper Darby, PA.

Conover, D.F. and R.A. Ralston. 1959. Results of crop tree thinning and pruning in northern hardwood sapling stands after 19 years. J. For. 57:551-557.

Cottam, G. 1949. The phytosociology of an oak woods in southwestern Wisconsin. Ecol. 30(3):271-287.

Crow, T.R. and F.T. Metzger. 1987. Regeneration under selection cutting. In: R.D. Nyland, ed. Managing Northern Hardwoods. SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

Crow, T.R., C.H. Tubbs, R.D. Jacobs, and R.R. Oberg. 1981. Stocking and structure for maximum growth in sugar maple selection stands. US For. Serv. Res. Pap. NC-199.

Curtis, J.T. 1959. The Vegetation of Wisconsin. Univ. Wisc., Madison, WI.

Curtis, R.O. and F.M. Rushmore. 1958. Some effects of stand density and deer browsing on reproduction in an Adirondack hardwood stand. J. For. 56:116-121.

Dale, M.E. 1968. Growth response from thinning young even-aged white oak stands. US For. Serv. Res. Pap. NE-112.

Dale, M.E. 1972. Growth and yield predictions for upland oak stands. US For. Serv. Res. Pap. NE-241.

Dale, M.E. and D.E. Hilt. 1986. Thinning pole and small sawtimber mixed oak stands. In: H.C. Smith and M.C. Eye, ed. Guidelines for Managing Immature Appalachian Hardwood Stands. Proc. Workshop, May 28-30, 1986. W.Va. Univ., Morgantown, WV.

Dale, M.E. and D.L. Sonderman. 1984. Effect of thinning on growth and potential quality of young white oak crop trees. US For. Serv. Res. Pap.

NE-539.

Davis, R.S. 1988. A Simulation of the effects of repeated partial cutting on the structure and development of uneven-aged sugar maple stands in New York State. MS Thesis. SUNY Coll. Environ. Sci. and For., Syracuse, NY.

Dierauf, T.A. 1986. Thinning oak stands in Virginia. In:H.C. Smith and M.C. Eye, ed. Guidelines for Managing Immature Appalachian Hardwood Stands. Proc. Workshop, May 28-30, 1986. Univ. W.Va., Morgantown, WV.

Erdmann, G.G. 1987. Methods of commercial thinning in even-aged northern hardwood stands. In: R.D. Nyland, ed. Managing Northern Hardwoods. SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Pubi. 13 (ESF 87-002).

Ernst, R.L. 1987. Growth and yield following thinning in mixed-species Allegheny hardwood stands. In: R.D.Nyland, ed. Managing Northern Hardwoods. SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

Eyre, F.H. and W.M. Zillgitt. 1953. Partial cuttings in northern hardwoods of the Lake States. US Dep. Agr. Tech. Bull. 1076.

Ford-Robertson, F.C. 1971. Terminology of forest science, technology, practice and products. Soc. Am. For., Multilingual For. Terminol. Ser. No. 1.

Gilbert, A.M. and V.S. Jensen. 1958. A management guide for northern hardwoods in New England. US For. Serv., Northeast. For. Exp. Stn., Stn. Pap. 112.

Gingrich, S.F. 1971. Stocking, growth, and yield of oak stands. In: D. E. White and B.A. Roach, ed. Oak Symposium Proceedings. US For. Serv., Northeast. For. Exp. Stn., Upper Darby, PA.

Godman, R.M. 1968. Culture of young stands. In: Proceedings of the Sugar Maple Conference, 20-22 Aug. 1968, Mich. Technol. Univ., Houghton, MI.

Graney, D.L. and T.L. Rogerson. 1985. Growth of oak, ash, and cherry reproduction following overstory thinning of upland hardwood stands in the Boston Mountains of Arkansas. In: Fifth Cent. Hwd. For. Conf., April 15-17, 1985, Univ. Ill., Urbana-Champaign, IL.

Grisez, T.J. and M. Peace. 1973. Requirements for advance regeneration in Allegheny hardwoods - An intrim guide. US For. Serv. Res. Note NE-180.

Hansen, G. 1987. Choosing diameter distributions to aid in marking uneven-aged northern hardwood stands. In: R.D.Nyland, ed. Managing Northern Hardwoods. SUNY Coll. Environ. Sci. and For. Fac. For. Misc. Publ. 13 (ESF 87-002)

Hansen, G. and R.D. Nyland. u.d. Alternate structures for northern hardwoods under selection system. Unpubl. notes. SUNY Coll. Environ. Sci. and For., Syracuse, NY.

Huntley, J.C. and C.E. McGee 1982. Impact of fire on regeneration and wildlife habitat in upland hardwoods. In: Proceedings, 1982 Cony. Soc.Am. For., Sept. 19-22, 1982, Cincinnati, OH.

Jensen, V.S. 1943. Suggestions for the management of northern hardwood stands in the Northeast. J. For. 41:180-185.

Johnson, L.C. and R.P. Overton. 1984. Tree Improvement Plan for the Northeastern Area State and Private Forestry. US For. Serv. Northeast. Area State and Priv. For. Broomall, PA.

Johnson, P.S. 1974. Survival and growth of northern red oak seedlings following a prescribed burn. US For. Serv. Res. Note NC-177.

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

Johnson, P.S. and R.D. Jacobs. 1980. Northern red oak regeneration after preherbicided clearcutting and shelterwood removal cutting: 3 case histories. US For. Serv. Res. Pap. NC-202.

Johnson, V.J. 1984. Prescribed burning - requiem or renaissance? J. For. 82:82-91.

Kelty, M.J. 1987. Shelterwood cutting as an even-aged reproduction method. In: R.D. Nyland, a.l. Managing Northern Hardwoods. Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

Kelty, M.J. and R.D. Nyland. 1981. Regenerating Adirondack northern hardwoods by shelterwood cutting and deer density control. J. For. 79: 22-26.

Kirkham, K.B. and K.L. Carvell. 1980. Effect of improvement cuttings and thinnings on the understories of mixed oak and cove hardwood stands. W.Va. Univ., Agr. and For. Exp. Stn. Bull. 673.

Leak, W.B. 1963. Effects of seedbed, overstory, and understory on white ash regeneration in New Hampshire. US For. Serv. Res. Pap. NE-2.

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

Leak, W.B., D.S. Solomon, and S.M. Filip. 1969. A silvicultural guide for northern hardwoods in the Northeast. US For. Serv. Res. Pap. NE-143.

Leak, W.B. and D.S. Solomon. 1975. Influence of residual stand density on regeneration in northern hardwoods. US For. Serv. Res. Pap. NE-310.

Leak, W.B. and R.W. Wilson Jr. 1968. Regeneration after cutting of old-growth northern hardwoods in New Hampshire. US For. Serv., Northeast. For. Exp. Stn., Stn. Pap. 103.

Lees, J.C. 1987. Clearcutting as an even-aged reproduction method. In: R.D.Nyland, ed. Managing Northern Hardwoods. SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

Mader, S.F. and R.D. Nyland. 1984. Six-year response of northern hardwoods to selection system. North. J. Appl. For. 1:87-91.

Marquis, D.A. 1965a. Regeneration of birch and associated hardwoods after patch cutting. US For. Serv. Res. Pap. NE-32.

Marquis, D.A. 1965b. Controlling light in small clear-cuttings. US For. Serv. Res. Pap. NE-39.

Marquis, D.A. 1967. Clearcuttig in northern hardwoods: Results after 30 years. US For. Serv. Res. Pap. NE-85.

Marquis, D.A. 1978. Application of uneven-aged silviculture and management on public lands. In: Uneven-aged Silviculture and Management in the United States. US For. Serv., Timber Manage. Res., Wash., DC.

Marquis, D.A. 1986. Thinning Allegheny hardwood pole and small sawtimber stands. In: H.C. Smith and M.C. Eye, ed. Managing Immature Appalachian Hardwood Stands. Proc. Workshop, 28-30 May 1986, W.Va. Univ., Morgantown, WV.

Marquis, D.A. 1987. Assessing the adequacy of regeneration and understanding early development patterns. In: R.D. Nyland, ed. Managing Northern Hardwoods. SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

Marquis, D.A., R. L. Ernst, and S. L. Stout. 1984. Prescribing silvicultural treatments in hardwood stands of the Alleghenies. US For. Serv. Gen. Tech. Rpt. NE-96.

Marquis, R.W., S. Weitzman, and C.J. Holcomb. 1954. Cutting mountain hardwood stands. US For. Serv., Northeast. For. Exp. Stn., Stn. Pap. 73.

Maynard, C.A., R.P. Overton, and L.C. Johnson. 1987. The silviculturist's role in tree improvement in northern hardwoods. In: R.D. Nyland, ed. Managing Northern Hardwoods. SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

McGee, C.E. 1975. Regeneration alternatives in mixed oak stands. US For. Serv. Res. Pap. SE-125.

McGee, C.E. and D.L. Bivens. 1984. A billion overtopped white oaks - Assets or liabilities? S. J. Appl. For. 8(4):216-220.

McQuilkin, R.A. 1979. Use of prescribed fire in upland oak-hickory forests to enhance oak reproduction. Unpubl. draft, US For. Serv., N. Cent. For. Exp. Stn., Columbia, MO.

Merritt, C. 1979. An overview of oak regeneration problems. In: H.A. Holt and B.C. Fischer, ed. Regenerating Oaks in Upland Hardwood Forests. Proc. J.S. Wright For. Conf., Feb 22-23, 1979, W. Lafayette, IN.

Metzger, F.T. and C.H. Tubbs. 1971. The influence of cutting method on regeneration of second-growth northern hardwoods. J. For. 69:559-564.

Nyland, R.D. 1986a. Logging damage during thinning in even-aged hardwood stands. H.C. Smith and M.C. Eye, ed. Managing Immature Appalachian Hardwood Stands, Proc. Workshop 28-30 May,1986. W.Va. Univ., Morgantown, WV.

Nyland, R.D. 1986b. Important trends and regional differences in silvicultural practice for northern hardwoods. In: G.D. Mroz and D.D. Reed, ed. The Northern Hardwood Resource: Management and Potential. Proc. Conf., Aug. 18-20, 1986. Mich. Tech. Univ., Houghton, MI.

Nyland, R.D. 1987. Selection system and its application. In: R.D. Nyland, ed. Managing Northern Hardwoods. SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

Nyland, R.D., P.J. Craul, D.F. Behrend, H.E. Echelberger, W.J. Gabriel, R.L. Nissen Jr., R. Uebler, and J. Zarnetske. 1976. Logging and its effects in northern hardwood stands. SUNY Coll. Environ. Sci. and For., Appl. For. Res. Inst., AFRI Res. Rpt. 3.

Nyland, R.D. and W.J. Gabriel. 1971. Logging damage to partially cut hardwood stands in New York State. SUNY Coll. Environ. Sc!. and For., Appl. For. Res. Inst., AFRI Res. Rpt. 5.

Nyland, R.D. and H.J. Irish. 1971. Early response to clearcutting in northern hardwoods. SUNY Coll. Environ. Sci. and For., Appl. For. Res. Inst., AFRI Res. Note 2.

Nyland, R.D., D.A. Marquis, and D.K. Whittemore. 1981. Northern hardwoods. In: D.H. Van Lear, ed. Choices in Silviculture for American Forests. Soc. Am. For., Wash., DC.

Nyland, R.D., L.P Abrahamson, and K.B. Adams. 1982. Use of prescribed fire for regenerating red and white oak in New York. In: America's Hardwood Forests. Proc. Soc. Am. For. Natl. Cony., Cincinnati, Ohio, Sept. 19-22, 1982.

Richards, N.A. and C.E. Farnsworth. 1971. Effects of cutting level on regeneration of northern hardwoods protected from deer. J. For. 69: 230-233.

Roach, B.A. 1974. Selection cutting and group selection. SUNY Coll. Environ. Sci. and For., Appl. For. Res. Inst., AFRI Misc Rpt. No. 5.

Roach, B.A. 1971. Research needed for improved management of upland oaks. US For. Serv., Northeast. For. Exp. Stn., Upper Darby, PA.

Roach, B.A. 1977. A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings. US For. Serv. Res. Pap. NE-373.

Roach, B.A. and S.F. Gingrich. 1968. Even-aged silviculture for upland central hardwoods. US Dep. Agr., Agr. Handbk. 355.

Roberge, M.R. 1977. Influence of cutting method and artificial regeneration of yellow birch in Quebec northern hardwoods. Can. J. For. Res. 7:175-182.

Sage, R.W., Jr. 1986. Unwanted vegetation and its effects upon regeneration success. In: R.D. Nyland, ed., Managing Northern Hardwoods SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002). Syracuse, NY.

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 regeneration: Key to growth following harvest cutting. US For. Serv. Res. Pap. NC-79.

Sander, I.L. and F.B. Clark. 1971. Reproduction of upland hardwood forests in the Central States. US Dep. Agr., Agr. Handbk. 405.

Sander, I.L. and M.J. Williamson. 1957. Response of a mixed hardwood stand in eastern Kentucky to a harvest cutting. J. For. 55:291-293.

Sander, I.L., C. Merritt, and E.H. Tryon. 1981. Oak-hickory. In: D.H. Van Lear, ed. Choices in American Silviculture for American Forests. Soc. Am. For., Wash., DC.

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

Sander, I.L., P.S. Johnson, and R.F. Watt. 1976. A guide for evaluating the adequacy of oak advance reproduction. US For. Serv. Gen. Tech. Rpt. NC-23.

Smith, H.C. 1981. Diameters of clearcut openings influence central Appalachian hardwood stem development - A 10-year study. US For. Serv. Res. Pap. NE-476.

Smith, H.C. and N.I. Lamson. 1986. Cultural practices in Appalachian hardwood sapling stands -- If done, how to do them. In: H.C. Smith and M.C. Eye, ed. Managing Immature Appalachian Hardwood Stands. Proc. Workshop, 28-30 May 1986, W.Va. Univ., Morgantown, WV.

Smith, H.C. and N.I. Lamson. 1987. Pre-commercial treatment of 15- to 40-year-old northern hardwood stands. In: R.D.Nyland, ed. Managing Northern Hardwoods, SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

Solomon, D.S. 1977. The influence of stand density and structure on growth of northern hardwoods in New England. US For. Serv. Res. Pap. NE-362.

Solomon, D.S. and W.B. Leak. 1986. Simulated yields for managed northern hardwood stands. US For. Serv. Res. Pap. NE-578.

Sonderman, D.L. 1984. Quality response of even-aged 80-year-old white oak trees after thinning. US For. Serv. Res. Pap. NE-543.

Stout, S.L. 1987. Planning the right residual: Relative density, stand structure, and species composition. In: R.D. Nyland, ed. Managing Northern Hardwood. SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13 (ESF 87-002).

Trimble, G.R., Jr. 1961. Managing mountain hardwoods - A ten-year appraisal.

US For. Serv., Northeast. For. Exp. Stn., Stn. Pap. 143.

Trimble, G.R., Jr. 1968. Growth of Appalachian hardwoods as affected by site and residual stand density. US For. Serv. Res. Pap. NE-98.

Trimble, G.R., Jr. 1973. The regeneration of central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice. US For. Serv. Res. Pap. NE-282.

Trimble, G.R., Jr. and D.B. Findley. 1963. Thirteen years of forestry research in West Virginia. US For. Serv. Res. Pap. NE-5.

Trimble, G.R., Jr., J.J. Mendel, and R.A. Kennell. 1974. A procedure for selection marking in hardwoods: Combining silvicultural considerations and economic guidelines. US For. Serv. Res. Pap. NE-292.

Trimble, G.R., Jr. and G. Hart. 1961. An appraisal of early reproduction after cutting in northern Appalachian hardwood stands. US For. Serv., Northeast. For. Exp. Stn., Stn. Pap. 162.

Tryon, E.H. and K.L. Carvell. 1958. Regeneration under oak stands. W.Va. Univ. Agr. and For. Exp. Stn. Bull. 424T.

Tubbs, C.H. 1968. The influence of residual stand densities on regeneration in sugar maple stands. US For. Serv. Res. Note NE-47.

Tubbs, C.H. 1973. Allelopathic relationships between yellow birch and sugar maple seedlings. For. Sci. 19:139-145.

Tubbs, C.H. 1977a. Natural regeneration of northern hardwoods in the northern Great Lakes REgion. US For. Serv. REs. Pap. NC-150.

Tubbs, C.H. 1977b. Manager's guide for northern hardwoods in the North Central States. US For. Serv. Gen. Tech. Rpt. NC-39.

Wallenberg, W.G. 1956. Three methods of rehabilitation for depleted Appalachian hardwood stands. J. For. 51:874-880.

Walters, R.S. and R.D. Nyland. 1988. Clearcutting central New York hardwood stands. N. J. Appl. For. (in press).

Watt, R, K.A. Brinkman, and B.A. Roach. 1979. Oak-hickory. In: Silvicultural Systems for the Major Forest Types of the United States. US Dep. Agr., Agr. Handbk. No. 445.

Weitzman, S. and G.R. Trimble, Jr. 1957. Some natural factors that govern the management of oaks. US For. Serv., Northeast. For. Exp. Stn., Stn. Pap. 88.

Wendell, G.W. and H.C. Smith. 1986. Effects of a prescribed fire in a central Appalachian oak-hickory stand. US For. Serv. Res Pap. NE-RP-594.

Wendell, G.W. and G.R. Trimble Jr. 1968. Early reproduction after seed-tree harvest cuttings in Appalachian hardwoods. US For. Serv. Res. Pap. NE-99.