Prescribed Fire and Oak Regeneration

by D. H. Van Lear, Bowen Professor of Forestry, Clemson University
Clemson, South Carolina, USA

P. H. Brose, Research Forester, USDA Forest Service
Warren, Pennsylvania, USA

and

P. D. Keyser, Wildlife Biologist, Westvaco Corporation
Rupert,West Virginia, USA

Exclusion of periodic surface fires from mixed hardwood stands in the United States for over 70 years changed the character of forests growing on good quality sites. Removal of fire from these ecosystems contributed to the gradual invasion of oak stands by shade-tolerant, fire-intolerant species into the understory and midstory, preventing successful establishment of oak species on good quality sites. When canopy-gap type disturbances occur, well established oak regeneration is not available to develop into mid- and upper canopy trees. If there is a major disturbance in the overstory of these mixed stands, pioneer shade-intolerant species such as yellow-poplar (*Liriodendron tulipifera* L.) out-compete oak regeneration and dominate the next stand. Periodic underburning in mixed hardwood stands creates conditions conducive for oak regeneration and establishment, but require a relatively long regeneration period. We recently developed a shelterwood-burn technique, which mimics the natural disturbance regime that historically favored oaks. It can be used on productive upland sites to enhance the competitive position of oaks in the advance regeneration pool. This paper presents silvicultural guidelines for applying the technique and discusses several options to meet management objectives of different landowners.

Introduction

Regenerating oaks (*Quercus* L. spp.) on productive upland sites has been a major silvicultural challenge for decades in eastern hardwood forests. In the dense shade of mature mixed-hardwood stands, oak seedlings and seedling

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sprouts do not develop into competitive stems either because of poor initial establishment of oak seedlings or the slow juvenile growth of oak advance regeneration if present (Loftis 1983; Abrams 1992, Lorimer 1993, Loftis and McGee 1993). Overstory removal by either partial or complete cuttings releases well-established shade tolerant regeneration, such as red maple, and facilitates establishment of fast-growing shade intolerant seedlings like yellow-poplar. Oak species generally become a minor component or altogether absent on good quality sites as the new stand develops (McGee 1979; Abrams 1992; Lorimer et al. 1994). Numerous researchers think this pattern of stand succession is a relatively recent phenomena, developing in the past 75 years or so, and is tied to the exclusion of fire from eastern hardwood forests (Little 1974; Van Lear and Johnson 1983; Crow 1988; Van Lear and Waldrop 1989; Abrams 1992; Lorimer 1993).

In this paper, we briefly describe the fire history of the eastern United States and how oaks adapted to frequent burning. Attempts to regenerate oaks on good quality sites using prescribed burning in relatively undisturbed mature stands will be discussed. Finally, we will describe a new techniqueBthe shelterwood-burn method—that has proved successful in regenerating oaks in the southern Piedmont. This new regeneration method to regenerate oaks utilizes partial harvesting, followed by prescribed fire and mimics disturbance regimes that historically favored oak.

Fire in the Eastern United States

After the Wisconsin glaciation peaked about 18,000 years ago and the Laurentide ice sheet

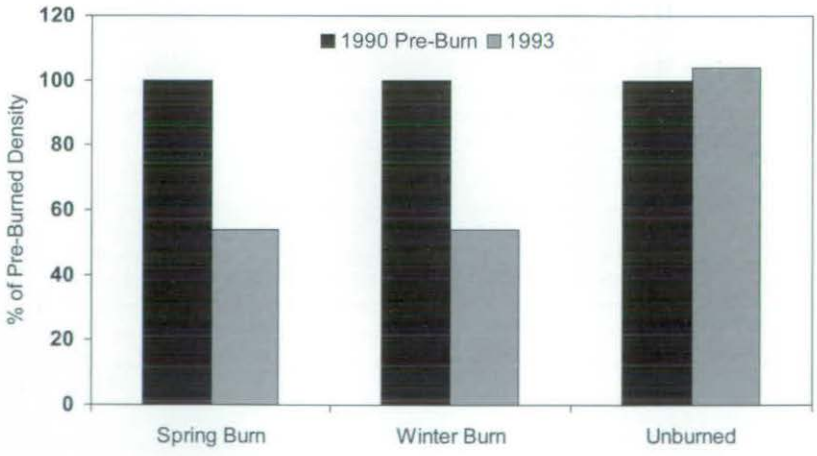

Figure 1. *Reduction of midstory/understory densities following three winter burns and one spring burn on the Clemson Experimental Forest.*

began to retreat, plant species gradually migrated northward in response to the warming climate. However, a factor other than the warming climate affected vegetative patterns that were developing during this time. At least 12,000 years ago and during this warming period, Indians arrived in the eastern United States (Williams 1989; Bonnickensen 2000). Prior to their arrival, lightning was the sole ignition source with most fires occurring in the growing season. Indians used fire in all seasons and vastly extended the influence of fire on vegetation throughout the eastern United States.

Demographers now estimate the Indian population of North America at the time of Columbus at about 18 million people (Dobyns 1983). They lived in generally small villages, although some towns had populations in the thousands, and their agricultural fields occupied the more productive bottomland sites along rivers. By 1500 AD, most eastern Indians were deriving more than half of their sustenance from agriculture (Williams 1989). When they burned their fields to clear the stubble or burned along their extensive river trail system, fires would have burned along a topographic gradient from mesic to xeric sites, ensuring that good quality oak sites would have been burned on a frequent basis.

Indians used fire for many reasons other than land clearing for agricultural crops and to facilitate travel. They used fire for hunting purposes, to stimulate berry production, to provide wildlife habitat, and as a defense against enemies (Williams 1989; Bonnicksen 2000). Through their widespread and frequent burning, Indians influenced the environment far out of proportion to their population. Their use of fire, a tradition subsequently carried on by European settlers (Hudson 1976; MacCleery 1992; Williams 1989), created an environment favorable for the establishment and maintenance of oaks on good quality sites.

In the early 1900s, suppression efforts of the U.S. Forest Service and state forestry commissions began to be successful in reducing the frequency, extent, and influence of fire (Van Lear and Waldrop 1989; MacCleery 1992). As fire was excluded, eastern forests changed dramatically (Lorimer 1993; Abrams 1992). Shade-tolerant and fire-intolerant species began to dominate forest understories, overstory densities increased, and fire-sensitive species moved upslope from moist coves to xeric slopes.

Why Fire Favors Oaks

Surface fires remove much of the mid- and understory strata in mature mixed hardwood stands, reducing shading and providing growing space for oak advance regeneratio. If such regeneration is greater than 2 inch at ground line, it is likely to survive burning by sending up new sprouts. Spring fires are especially effective in killing these lower strata trees (Barnes and Van Lear 1998), some of which die gradually over a several year period. Fire prepares a favorable seedbed for caching of acorns by squirrels and jays (Darley-Hill and Johnson 1981, Galford et al. 1989) and reduces surface soil moisture, which discourages establishment of mesophytic species (Barnes and Van Lear 1998). Frequent burning may control insect predators of acorns and new seedlings (Galford et al. 1989). All these fire effects create environments that favor oak regeneration on better quality sites.

Oaks, like many other fire-adapted species, encourage future surface fires because of the nature of their leaf litter. Fallen oak leaves remain curly, creating a porous fuelbed for surface fires. Unlike leaf litter of mesophytic species which forms a flat mat upon compaction and decays rapidly, oak leaf litter undergoes little decay during the winter, even in regions where snowpacks are heavy. Oak litter recurls after snowmelt, once again creating a porous fuelbed capable of carrying a surface fire during the spring fire season (Lorimer 1989).

Because of the complexity of forest ecosystems and the characteristics of fire (season, in-

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tensity, severity, fire-return interval, etc.), effects of fire in hardwood stands vary. Fires in stands of mixed composition have occasionally created oak-dominated stands (Roth and Hepting 1943; Carvell and Maxey 1969), while in other circumstances species composition in young stands has been altered very little by fire (Johnson 1974; McGee 1979; Augspurger et al. 1987).

Season of burning and fire intensity are important if oak regeneration is to be favored by fire. Season of burning affects the sprouting vigor of the plant. In the winter when root reserves of hardwood regeneration are highest, hardwoods have the greatest ability to sprout. In the growing season, root reserves are lower and sprouting vigor is less. Fire intensity is critical because certain species, such as the oaks, can survive higher intensity fires than their competitors (Waldrop et al. 1987; Brose and Van Lear 1998). Oaks tolerate fire better than most competitors because oak sprouts originate deeper in the soil because of acorn burial by animals and hypogeal germination (Burns and Honkala 1990; Hane 1998).

Fire is, of course, but one disturbance factor that affects vegetation. Fire often works in combination with other environmental forces, especially with wind or ice storms that break up the overstory canopy. When the upper canopy is reduced or removed by wind or ice, ecosystems are predisposed to fire (Myers and Van Lear 1998). Openings in the overstory increase insolation and drying of the fuels created by the overstory disturbance. The increased insolation also favors growth of fine fuels which help carry surface fires. Thus, as a result of overstory disturbance, fire was almost certain to occur because human ignition sources were so plentiful.

Understory Burning to Encourage Oak Regeneration

In the absence of periodic fire, fire-intolerant and shade-tolerant species dominate the growing space of mature mixed hardwood stands on good sites in much of the eastern United States. Oak reproduction, if present, is not competitive in such settings. Because these sites did regenerate to oaks early in the past century and fire was much more prevalent in the environment at that time (Williams 1989; MacCleery 1992), it would seem plausible that reintroducing understory fire into mature mixed oak stands would encourage oak regeneration. However, because of a long-standing professional bias against burning in hardwoods, foresters have been slow to study the possibilities of burning to encourage oak regeneration.

Based on preliminary findings of a study in the Piedmont of South Carolina, Van Lear and Watt (1993) developed a theoretical silvicultural prescription to encourage oak regeneration by understory burning in mature mixed hardwood stands near the end of the rotation. Barnes and Van Lear (1998) continued this study and found that one growing season burn was as effective as three winter fires in reducing density of competing understory and midstory stems (fig. 1). The number of oak rootstocks in the regeneration layer was increased by burning; root/shoot ratios of oaks were enhanced, and competitive woody species decreased. Burning xerified the surface soil, probably through increasing insolation and reducing the mulching effect of the forest floor, which favors oak over competitive mesophytic species. There was little visible damage to boles of overstory oaks from the fires, especially in the larger size classes, from these low intensity fires.

Since the Barnes and Van Lear paper, we have burned the spring burn plots for the second time. The understory and midstory strata have been further reduced and there is a dense layer of oak regeneration with little competition. The plots that received the three winter burns also have dense oak regeneration with little competition. Although oak regeneration was increased and competition was reduced by periodic understory burning, it appears that burning would have to be continued for a relatively long period, i.e., perhaps 10 years or so, before sufficient oaks of competitive size would be present in the advance regeneration. Such an approach is handicapped by the expense and risks of multiple prescribed fires, making it a rather unattractive option for many landowners and managers. Nevertheless, if no advance regeneration exists in a stand and prescribed fires are feasible, periodic understory burning provides a means to establish oak seedlings and seedling sprouts, while reducing oak competitors, thereby setting the stage for the following technique.

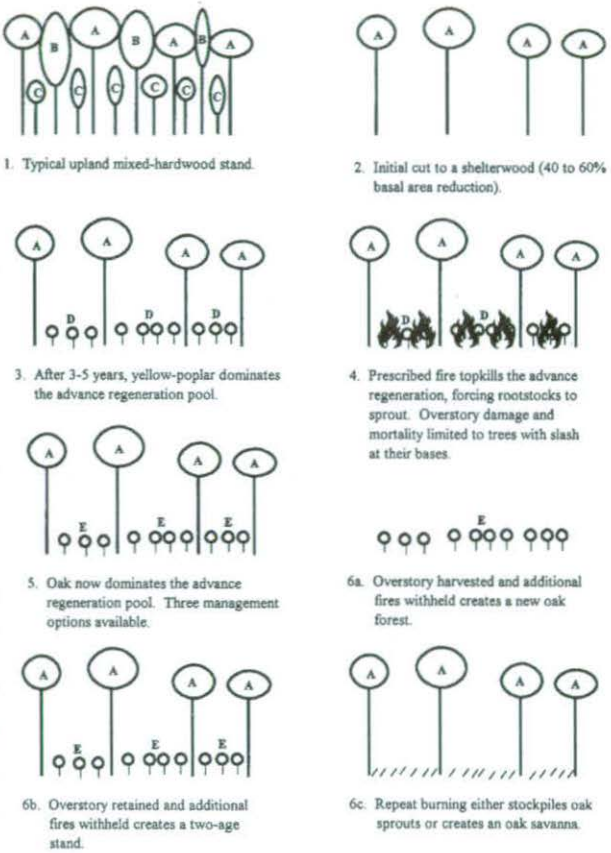

Figure 2. *Schematic diagram of the shelterwood-burn technique. A = high quality oaks; B = hickories, poor quality oaks, and yellow-poplars; C = American beech, flowering dogwood, and red maple; D = mixed hardwood regeneration dominated by yellow-poplar; and E = mixed hardwood regeneration dominated by oaks.*

The Shelterwood-Burn Method to Regenerate Oaks

A shelterwood-burn method (fig. 2) has recently been developed in the Piedmont of the southeastern United States to enhance the competitive position of oak regeneration in such stands (Keyser et al. 1996; Brose and Van Lear 1998; Brose et al. 1999a). This method uses an initial shelterwood harvest which removes roughly half of the overstory basal area. All yel-

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low-poplars are removed in this first cut of the two-cut shelterwood method, leaving the best dominant and codominant oaks. Following the initial shelterwood harvest is a 3- to 5-year waiting period, during which time the advance regeneration develops.

After this 3-5 year waiting period, a hot growing season fire is run through the advance regeneration. This type of fire kills most of the yellow-poplar regeneration and sets back many of the other competitors. Oak regeneration is favored because most of the oak seedlings/sprouts survive the fire by resprouting from their large root systems. Oak regeneration benefits from burning not only because it has relatively large root systems with large reserves of carbohydrates, but because its sprouting buds are protected from the heat of the surface fires due to their hypogeal germination (Burns and Honkala 1990). Squirrels and jays play an important role in burying acorns, ensuring that the root collars of well established seedlings are below ground.

Unless oak reproduction is relatively vigorous and free-to-grow, i.e., straight stems with large buds and at least 1.3 m tall with no major competitors within 3 m (Nix 1989), it is unlikely to compete well with fast growing species. Oaks resist root kill by fire better than yellow-poplar and other competitors, especially as fire intensity increases (Fig. 3) (Brose and Van Lear 1998). In our study of the shelterwood burn technique in Virginia=s Piedmont, density of free-to-grow oaks exceeded 800 stems/ha with high intensity spring fires. In contrast, yellow-poplar density was greatly reduced (up to 90%) by spring burning with high intensity flames. Winter burns provided little control of yellow-poplar and, even with a high intensity fire, oaks density did not reach 300 stems/ha. Summer fires provided substantial numbers of free-to-grow oaks, especially in the medium-high intensity levels. High intensity summer fires killed many of the smaller oak seedlings while low intensity summer fires failed to control competition.

Fires do not burn uniformly over entire treatment areas. This is but one reason why oak reproduction will not be uniform over an area treated with the shelterwood-burn method. We believe that if free-to-grow oaks exceed 370/ha and 60% or more of the stocking plots have at least one free-to-grow oak, the stand will regenerate to a predominantly oak stand. If one burn does not provide enough oak regeneration, additional burns may be prescribed. In many situations, decades of fire exclusion have allowed oak competitors to become so firmly established that oak regeneration may not be as plentiful as desired. If more oaks are desired, additional fires may be prescribed as dictated by leaf litter accumulation. Oak dominance of the advance regeneration will probably increase with repetitive spring burning at about 2-year intervals if such burns are deemed necessary.

Shelterwood Cutting vs. Clearcutting?

Would clearcutting followed in several years by a hot spring fire be as successful in favoring oak regeneration as shelterwood cutting? We believe that a shelterwood cut is the essential first step in this technique, for several reasons. First, the shelterwood continues to produce oak litter which creates the continuous fine fuel bed necessary to carry the subsequent fire. Secondly, if clearcutting had been used, yellow-poplar foliage, which decays quickly and lies flatBthus a poor medium for carrying surface

fires, would dominate the forest floor. Thirdly, shading from the shelterwood prevents yellow-poplar regeneration from growing so large during the interval before burning that it could not be killed by fire (Hane 1999).

The Waiting Period: Is it Necessary?

Why is it necessary to wait several years after the initial shelterwood cut before burning? A major reason for waiting is that, in the Piedmont, yellow poplar is usually the species that develops most prolifically following a major stand disturbance, such as the initial shelterwood cut. Because its seed remains viable for years in the duff and it is a pioneer species, it grows densely and vigorously during the first few years after disturbance and dominates the advance regeneration. Intolerant competitors of oak, such as yellow-poplar, put most of their energy into top-growth during this preburn period (Hane 1998). Conversely, oak regeneration, which should be present at the time of the initial shelterwood cut if this technique is to succeed, puts a relatively high proportion of its energy into root growth during this interval between shelterwood cutting and burning and, therefore, is able them to sprout vigourously after burning. In the absence of the forthcoming disturbance of burning, oak regeneration could not compete with the fast growing yellow-poplar seedlings. Without this waiting period, these differences in growth patterns that affect species mortality rates from the burn would not exist.

The waiting period also allows logging slash to settle and become less of a hazard to burn. If heavy logging slash from the initial shelterwood cut rests against the bole of residual trees, it should be lopped or pulled away to prevent bole damage from flareups or long fire residence times when the area is burned. A clause in the logging contract can easily take care of this potential problem. Actually, the distance between residual trees after the initial cut is generally great enough that directional felling should prevent most tops from being in close proximity to boles of residual trees (Brose and Van Lear 1998; Brose et al. 1999a). The waiting period also allows residual overstory trees to recover from the shock of the initial cut before they will be stressed again by burning.

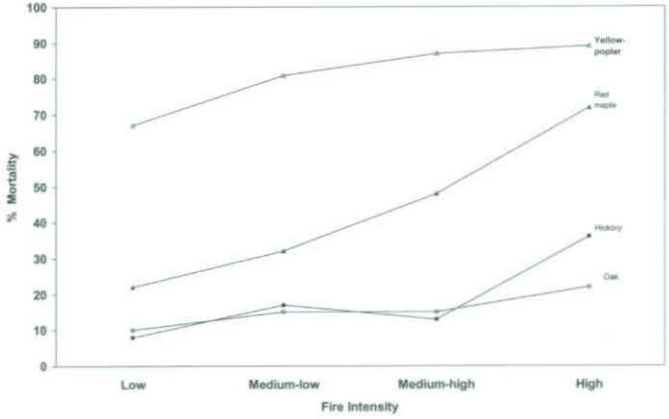

Figure 3. *Mortality (%) of hickory, oak, red maple, and yellow-poplar advance regeneration as fire intensity increases within spring prescribed burns conducted in shelterwood stands.*

Management Options with the Shelterwood-Brun Method

The shelterwood-burn method is attractive to landowners because the initial cut of the

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shelterwood method produces immediate income. A small portion of the profit is then used to pay for the prescribed burn. Removal of the shelterwood after burning is at least as profitable as the initial cut because the best oaks were retained and some probably increased in value during the intervening years before final harvest. However, the shelterwood-burn method can be used to accomplish objectives other than timber managment (Brose et al. 1999).

The shelterwood-burn method can be used by wildlife managers to sustain hard mast production and provide palatable browse during the regeneration period. The classic structure of the shelterwood can be maintained while stockpiling oak regeneration with periodic burns (Brose et al. 1999b). Many upland game and non-game species utilize the mast, browse, and cover in a regenerating shelterwood (Brose et al. 1999b; Lanham et al. 2000).

The shelterwood-burn method could be used to restore fire-maintained ecosystems (Brose et al. 1999b). Frequent growing season burns after the initial shelterwood cut would gradually reduce the density and size of woody regeneration. This treatment would create a hardwood woodland or savannah, two habitats that have become increasingly rare in the eastern United States after decades of fire exclusion (Buckner 1983; Pyne 1982; Van Lear and Waldrop 1989; Abrams 1992).

The shelterwood-burn method was developed in the southern Piedmont of the United States. Would the technique be successful in other physiographic regions and on different sites? Some research suggests that it would. In Wisconsin, two spring burns reduced densities of sugar maple (*Acer saccharum* Marsh.) and hop hornbeam (*Ostrya virginiana* (Mill.) K. Koch.) by 80% on mesic sites, while density of northern red oak (*Quercus rubra* L.) increased (Kruger 1992). Repeated burning in oak-pine communities on xeric sites in the Cumberland Plateau reduced regeneration of red maple and other non-oak species and promoted chestnut oak (*Quercus montana* Willd.) regeneration (Arthur et al. 1998). Ward and Gluck (1999), in Connecticut, observed that burning several years after a shelterwood harvest favored oaks and reduced competition from birch and shrubs. Hot fires in mountain laurel thickets in the Northeastern United States that opened canopies, i.e., a disturbance similar to a shelterwood harvest, allowed oak reproduction to grow past the dense shrub layer (Moser et al. 1996).

Conclusions

Until the early decades of the past century, fire played a major role in maintaining oak-dominated forests for millennia in the eastern United States. As a result of fire exclusion, oak forests on good quality sites have been in decline for decades as more shade-tolerant species gradually succeed oaks or shade-intolerant species outgrew them after major upper canopy disturbances.

Foresters have been reluctant to prescribe fire in hardwood stands because of fire of damaging boles of high-value trees. Thus, practical silvicultural prescriptions using fire for oak regeneration have been lacking. Periodic understory burning in mature mixed hardwood stands creates environmental conditions which favor oak regeneration. However, a number of burns over a decade or so are required for this method to be successful.

A shelterwood-burn method has recently been developed in the southern Piedmont of the

United States which has proved successful in regenerating oaks in mixed hardwood stands on good quality sites. This technique reduces the density and vigor of oaks competitors, especially if growing season burns of relatively high intensity are used. Oak regeneration allocates a relatively high proportion of its energy to roots following the initial shelterwood cut and sprouts vigorously following the subsequent burn. It mimics a disturbance pattern (i.e., partial overstory disturbance followed by fire) that has shaped the composition of eastern forests for millennia.

The shelterwood-burn method is economically attractive when timber production is the primary management objective. However, the technique also should be attractive for wildlife managers who want to create two-aged stands or maintain a shrub layer beneath a mature overstory canopy. Ecologists may also be interested in using a modified version of the technique to restore open oak woodland conditions by burning frequently in the growing season to favor a herbaceous layer of warm-season grasses and forbs.

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