UPLAND OAK ECOLOGY AND MANAGEMENT

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Abstract—Of the many disturbance factors that shaped hardwood forests in the eastern United States, fire was perhaps the most important. Fires ignited by Native Americans and lightning played a dominant role in sustaining oak (*Quercus* spp.) forests throughout the Central Hardwood Region. Prior to logging at the turn of the last century, fires in the region were mostly light to moderate intensity surface fires. Exclusion of frequent surface fires for over 70 years has changed the character of these previously open forests and contributed to the gradual invasion of oak stands by shade-tolerant, fire-intolerant species. Although upland oaks are more easily maintained on poor quality sites, sustaining oak species on good quality sites is difficult. When canopy-gap type disturbances occur on good sites, oak regeneration is not competitive enough to grow into the mid- and upper canopy. If there is a major disturbance in the overstory of these mixed stands, pioneer shade-intolerant species such as yellow-poplar (*Liriodendron tulipifera*)out-compete oak regeneration and dominate the next stand. Periodic underburning in mixed hardwood stands creates conditions similar to those prior to fire exclusion and are conducive to oak regeneration and establishment. A shelterwood-burn technique has recently been developed that can be used on productive upland sites to enhance the competitive position of oaks in the advance regeneration pool. Oaks are well adapted to tolerate fire and benefit from fire at the expense of their competitors. Foresters can use prescribed fire where feasible to sustain oaks in a variety of ecosystem conditions ranging from fully stocked timber stands to open oak woodlands.

INTRODUCTION

As the Wisconsin ice sheets retreated to the North toward the end of the Pleistocene Epoch, tundra and boreal vegetation that had dominated the Central Hardwood Region began to be replaced by hardwood species. Spurred on by the warming climate and the widespread use of fire by Native Americans, oaks (*Quercus* spp.) gradually dominated the region (Abrams 2002, Carroll and others 2002).

Fire, early man's only tool to manipulate the landscape, has been a major ecological process shaping the pattern, composition, and structure of vegetation in the eastern United States. Frequent fires set by man and lightning kept the forests open and park-like. Fire regimes characterized by frequent, low-intensity burns favored plants adapted to survive these types of fires. Oaks and other fire-adapted species benefitted from this fire regime and were able to out-compete less fire-adapted species and dominate much of the Central Hardwood Region.

Regenerating oaks on productive upland sites has been a major silvicultural challenge for decades in eastern hardwood forests (Carvell and Tryon 1961, Clark and Watts 1971, Loftis and McGee 1993). Could land-use history tell us why oaks cannot be regenerated on good quality sites? We know that fire was a much more dominant factor historically than it is today. In fact, foresters had long considered taboo the use of fire in hardwood management. However, in the last two decades, the use of fire by Native Americans to manage the landscape has become more appreciated (Pyne 1982, Buckner 1983, Pyne and others 1996, Bonnicksen 2000, Carroll and others 2002).

Recent books about oak ecology and management provide excellent treatments of these broad topics (Hicks 1998, Johnson and others 2002, McShea and Healy 2002). Therefore, I will confine my remarks to the fire ecology of upland oaks and how fire can be used silviculturally to sustain oak forests in various ecological conditions.

LAND-USE HISTORY AND ITS ROLE IN SUSTAINING OAK FORESTS

Man is intimately linked to the distribution and dominance of oak in the Central Hardwood Region. About 12,000 years ago, Native Americans made their way into North America (Williams 1989, Bonnicksen 2000, Carroll and others 2002). They used fire in many ways because it helped them survive and improved their quality of life. Over thousands of years, the American Indian became expert in using fire for various purposes, e.g., for hunting, to concentrate game in convenient areas, to encourage fruit and berry production, to keep the woods open along major corridors of travel, to fire-proof their villages, and for many other uses (Williams 1989, Pyne and others 1996, Bonnicksen 2000). Anthropogenic burning was certainly more important than lightning-ignited fires in shaping the vegetative character of the Central Hardwood Region.

The Native American population of North America has been estimated as high at 18 million at the time of Columbus (Dobyns 1983). Their influence on the eastern forest was far out of proportion to their population density, primarily because of their use of fire (Hudson 1976). Because of their high populations and burning activities, Native Americans ensured that much of the Central Hardwood Region was relatively open woodlands, savannahs, and prairies. The eastern United States in 1500 was a managed landscape and had been for thousands of years (Buckner 1983, Williams 1989, MacCleery 1992, Pyne and others 1996, Carroll and others 2002)

Indians burned frequently, complementing lightning as an ignition source. Their burning extended the fire season beyond the "natural" lightning-fire season of summer. After

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Indian populations plummeted in the 16th and 17th centuries from exposure to European diseases, their level of burning declined and the forest became uncommonly dense (Carroll and others 2002).

Early European settlers displaced the Indians, but continued using fire for many of the same reasons, i.e., to clear the woods of underbrush, to expose nuts, to clear agricultural fields, and to enhance grazing. Not until the early decades of the 20th century were there serious efforts to exclude fire as an ecological process in eastern North America. However, burning was still a common practice into the 1940s and 50s in the Southern Appalachian Mountains and the Ozark Highlands (Pyne and others 1996, Carroll and others 2002).

Widespread attempts to exclude fire, combined with exploitive logging of early successional species, e.g., shortleaf pine (*Pinus echinata*) from the Ozark highlands, enabled the modern oak forest to develop rapidly across much of eastern North America (Dey 2002). An era of fire exclusion had begun that would produce different environments from those that had existed in previous millennia and which would have numerous unexpected consequences (Brose and others 2002).

Now oaks are not being sustained on good quality sites (Healy and others 1997, McWilliams and others 2002). Land-use history — a history based not only on written history (Hudson 1976, Dobyns 1983, MacCleery 1992) but also on nature's history as recorded in sediment cores showing pollen and charcoal distribution for thousands of years (Watts 1983, Delcourt and Delcourt 1987, Carroll and others 2002), clearly demonstrates the important role fire once played in the eastern United States. It is reasonable to conclude that a policy of fire exclusion over much of the past century is a major cause of our inability to regenerate oaks on better sites today. Of course, there are other factors that are important in certain areas, especially over-browsing by deer (Lorimer 1993). But exclusion of fire, in my opinion, is the primary reason for the disturbing trend of oaks failing to regenerate on good quality sites throughout much of the Central Hardwood Region.

ADAPTATIONS OF OAKS TO FIRE

Fire has been so ubiquitous and exerts such profound influences on the environment that it is reasonable to assume that natural selection favored individuals in populations that could best survive fire (Pyne and others 1996). Plant species that evolved with fire adapted by developing attributes that increased their chances of survival in those environments.

Among the fire-adaptations of oaks is their tenacious ability to resprout repeatedly, after other species have died, from root collar buds following topkill by fire (Waldrop and others 1987). The ability to resprout time after time after their tops are killed would improve oak survival rates because they would continually occupy the same growing space over long periods of time, beyond the elimination of other species.

Oaks have thick bark which insulates their living cambium from the heat of surface fires (Hare 1965). Competing species such as maples (*Acer* spp.) and American beech (*Fagus grandifolia*) have thinner bark, especially when young, and are quite susceptible to fire damage or mortality.

Because acorns are often buried by squirrels and/or jays (*Sciuridae* and *Corvidae*) and germination is hypogeal, root-collar buds of oaks are well protected from the heat of surface fires (soil is a poor conductor of heat). Many of oaks' competitors, such as yellow-poplar, have seeds that germinate on the soil surface and thus have exposed buds which are more susceptible to mortality from fire (Brose and Van Lear 1998, Brose and others 1999a, Brose and others 1999b). A major reason why oaks tolerate fire better than most competitors is because oak sprouts often originate beneath the soil surface (Burns and Honkala 1990).

Some adaptations not only allow plants to survive fire but also play a major role in predisposing plant communities to recurrent fire (Mutch 1970). Fallen oak leaves are resistant to decay and curl as they dry, providing a highly aerated fuel bed which encourages frequent surface fires. In contrast, leaves of fire-sensitive hardwoods like American beech, yellow-poplar, and maples lie flat on the ground and decay rapidly, preventing a flammable fuel bed from developing. Unless fire-adapted plant communities tend to promote recurrent fire, they are likely to be replaced by non-flammable communities (Bond and van Wilgen 1996).

MAJOR ECOLOGICAL DISTURBANCES AFTER EUROPEAN SETTLEMENT

Europeans began settling the Central Hardwood Region over 300 years ago. Since then, there have been many types of anthropogenic disturbances, including logging, fuelwood cutting, charcoal production, grazing, agriculture, and development in the region (Buckner 1992, Hicks 1998, Dey 2002). Timber exploitation began in the mid 1800s when the steam engine allowed the entire region to be heavily logged. Often harvests were followed by intense and severe fires in the heavy logging debris, which created coppice forests dominated by oaks (Clatterbuck 1991, Dey 2002). These intense and often severe fires differed from fires of previous millennia which, because of their frequency, were generally low intensity burns in light fuels (Carroll and others 2002).

In the early 1900s the chestnut blight (*Cryphonectria parasitica*) was introduced into New York's Botanical Garden. By the late 1930s, the blight had eliminated chestnut (*Castanea dentata*) as an important component in eastern forests, although its snags and downed logs continue to provide habitat for wildlife to this day. American chestnut was dominant in mixed stands throughout much of the Central Hardwood Region occupying a broad swath from the Appalachian Mountains to Arkansas and south into Georgia, Alabama, and Mississippi. Chestnut was one of the most economically, as well as ecologically, important species in the region and was generally replaced by oak forest associations (Hicks 1998, Johnson and others 2002, McShea and Healy 2002). However, on good quality sites in the southern Appalachians, heavily logged chestnut-dominated stands often succeeded to associations dominated by mesophytic species (Vandermast and Van Lear 2002).

Catastrophic wildfires around the turn of the last century in the Lake States and Rocky Mountains aroused the country's attention and concern. Cutover forests in the southeastern Coastal Plain burned so frequently that forest regeneration was often impossible. Slash fires following logging in the Appalachian Mountains burned severely with devastating offsite effects, such as erosion, sedimentation, and smoke pollution. The public began to see fire as an enemy to be suppressed at all costs (Pyne and others 1996, Johnson and Hale 2002). In the early decades of the 20th century, a policy of fire exclusion began that created ecosystems different from those fire-dependent ecosystems that had existed in previous millennia.

Over-zealous fire exclusion in ecosystems that had previously been fire dependent is a form of disturbance, i.e., a state of disorder which changes the very nature of those ecosystems. Exclusion of fire had many unexpected and undesirable consequences, including endangerment of fire-dependent ecosystems and many species that live in them (Landers and others 1995, Brennan and others 1998, Brose and others 2002). On good quality sites in the southern Appalachians, rhododendron (*Rhododendron maximum*) has encroached on upland sites and now threatens the diversity and productivity of cove forests (Vandermast and Van Lear 2002). The spread of rhododendron is, in part, related to the exclusion of fire in the mountains.

SUSTAINING OAK FORESTS WITH FIRE

Oak forests are in trouble. They are being replaced by other species, especially on good quality sites because of natural succession trends and because we have been unable to consistently regenerate oak species on these sites following harvest. Fire has been excluded in many areas of the Central Hardwood Region. In some areas, unnaturally high deer herds prevent oak regeneration because oaks are preferentially browsed by white-tailed deer (Healy 1997). Insect pests, e.g., the red oak borer, and diseases, e.g., a root rot caused by the fungus Armillaria, contribute to the problem of oak decline in the Ozarks (Lawrence and others 2002). Other papers in the proceedings of this conference cover these latter topics, so I will address the use of fire to regenerate oak-dominated stands.

In the dense shade of mature mixed-hardwood stands, oak seedlings and seedling 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 often releases well-established shade tolerant regeneration, such as red maple, or 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 1993). 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).

Repeated surface fires, especially in the growing season, remove much of the mid- and understory strata in mature mixed hardwood stands, reducing shading and providing growing space for oak advance regeneration. Spring fires are especially effective in killing these lower strata trees (Barnes and Van Lear 1998), some of which die gradually over several years. If oak advance regeneration is >½ inch at ground line, it is likely to survive burning by sending up new sprouts. Fire prepares a favorable seedbed for caching of acorns by squirrels and jays (Darley-Hill and Johnson 1981, Galford and others 1989) and may reduce surface soil moisture, which discourages establishment of mesophytic species (Barnes and Van Lear 1998). Frequent burning may also control insect predators of acorns and new seedlings (Galford and others 1989). All these fire effects create environments that favor oak regeneration on better quality sites.

Because forest ecosystems are complex and fire regimes vary (season, intensity, severity, fire-return interval, etc.), effects of fire in hardwood stands also vary. Single fires in mixed hardwood stands have occasionally created oak-dominated stands (Roth and Hepting 1943, Carvell and Maxey 1969) but sometimes species composition in young stands has been little altered by single fires (Johnson 1974, McGee 1979, Augspurger and others 1987). Many earlier studies, mine included, failed to adequately document fire behavior characteristics and other features of the treatment fires.

Season of burning and fire intensity are important considerations if oak regeneration is to be favored by fire. Season of burning affects sprouting vigor. In the winter when root reserves are highest, hardwoods have the greatest ability to sprout following topkill. 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 and others 1987, Brose and Van Lear 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 fuels, as well as favor growth of fine fuels which help carry surface fires.

UNDERSTORY BURNING TO ENCOURAGE OAK REGENERATION

Van Lear and Watt (1993) described a theoretical silvicultural prescription to encourage oak regeneration in the Piedmont of South Carolina by repeated understory burning in mature mixed hardwood stands near the end of the rotation. Barnes and Van Lear (1998) continued this study and found that oak rootstocks in the regeneration layer were increased, root/shoot ratios of oaks were enhanced, and competitive woody species decreased by repeated burning. Understory and midstory density was reduced by about 50 percent. Although boles of small diameter (5 to 10 inches) trees were often damaged by repeated burning, there was little visible damage to boles of large overstory oaks from these low intensity fires.

Understory burning must be continued at 2-3 year intervals for perhaps 10 years or so before sufficient oaks of competitive size will be present in the advance regeneration. In addition, seed-producing individuals that are vigorous competitors of oak, such as yellow-poplar, should be harvested at the beginning of the burning program. The initial fire will stimulate germination of yellow-poplar seed stored in the duff but subsequent fires will kill these small seedlings. Repeated underburning is handicapped by the expense and risks of multiple prescribed fires (Van Lear and Brose 2002). Nevertheless, if no oak advance regeneration exists in a stand and prescribed fires are feasible, periodic understory burning provides a means to encourage establishment of oak seedlings and seedling sprouts, while reducing competitors.

THE SHELTERWOOD-BURN METHOD TO REGENERATE OAKS

A shelterwood-burn method was recently developed in the Piedmont of Virginia to enhance the competitive position of oak regeneration in such stands (Keyser and others 1996, Brose and Van Lear 1998, Brose and others 1999a). Although developed outside the Central Hardwood Region, this method may be effective there and should be tested. The initial shelterwood harvest removes roughly half of the overstory basal area, leaving the best dominant and co-dominant oaks. In this first cut, all yellow-poplars are removed. Following this partial harvest is a 3- to 5-year waiting period, during which time the advance regeneration develops. Generally the advance regeneration on good sites will be dominated by species other than oaks. The third step occurs after the waiting period when a relatively hot growing season burn is run through the advance regeneration.

A growing season fire in early spring kills most of the yellow-poplar regeneration and sets back other competitors. Red maple, for example, requires hotter fires to achieve desired mortality rates (Brose and Van Lear 1998). Oak regeneration is favored because oak seedlings/sprouts, many of which have grown to a ground-line diameter >0.5 inch following the initial shelterwood cut, survive the fire by vigorous resprouting from their relatively large root systems.

Oak seedling/sprouts with large root/shoot ratios are capable of vigorous sprouting and growth after the spring burn if adequate light is available, which the fire provides (Brose and Van Lear 1998). In our study of the shelterwood-burn technique in Virginia's Piedmont, density of free-to-grow oaks exceeded 300 stems per acre with high intensity spring fires, while yellow-poplar density was reduced up to 90 percent. Low-intensity winter burns provided little control of yellow-poplar. Summer fires provided substantial numbers of free-to-grow oaks in the medium-high intensity levels, although many of the smaller oak seedlings were killed because they were not of sufficient size to tolerate the heat.

Additional burns may be prescribed if oak regeneration is not adequate after one burn. In many situations within the Central Hardwood Region and beyond, decades of fire exclusion have allowed oak competitors to become so firmly established that oak regeneration may not be as plentiful as desired. Oak dominance of the advance regeneration should increase with repetitive spring burning if such burns are deemed necessary.

A shelterwood cut is the essential first step in this technique because the shelterwood produces oak litter which creates a flammable fine fuel bed capable of carrying the subsequent fire. Clearcutting would produce a forest floor dominated by less flammable foliage. Shading from the shelterwood also prevents yellow-poplar regeneration from growing so large during the interval before burning that it could not be killed by fire (Hane 1999).

Although research on the shelterwood-burn technique was done in the Piedmont where yellow-poplar is the major competitor, other species are serious competitors in the Central Hardwood Region. Competitive species may exhibit either exploitive or conservative ecological strategies, depending upon the type of disturbance, to enhance their chances of survival (Bormann and Likens 1979, Johnson and others 2002). Most oak species are relatively conservative and do not allocate large portions of photosynthate to top-growth following large-scale overstory disturbances, as do many of their competitors.

Differences in developmental patterns probably explain why oaks benefit from the shelterwood-burn method. Yellow-poplar, for example, usually regenerates prolifically following 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 pool. During this time yellow-poplar regeneration allocates most of its energy to top-growth. Conversely, oak regeneration allocates much of its energy to root growth during the interval between shelterwood cutting and burning (Hane 1999). Oaks are therefore able to sprout vigorously after burning while yellow-poplar can not. Without burning, oak regeneration could not compete with the fast growing yellow-poplar seedlings.

During the 3 to 5 year waiting period, logging slash decomposes and become less hazardous to burn. Heavy logging slash from the initial shelterwood cut resting against boles of residual trees should be lopped or pulled away to prevent bole damage during burning. Distances between residual trees are generally great enough that directional felling can prevent most tops from being in close proximity to boles of residual trees (Brose and Van Lear 1998, Brose and others 1999a). Residual overstory trees can recover from the shock of the initial cut during the waiting period before they are stressed again by burning.

Management Options with the Shelterwood-Burn Method

There are several management options available to landowners following completion of the shelterwood-burn technique. The first option would be to harvest the shelterwood and release the oak-dominated regeneration. This method of timber management is economically attractive because the initial cut of the shelterwood method produces immediate income. A small portion of the profit is then used to pay for the prescribed burn a few years later. Removal of the shelterwood after burning is more profitable than the initial cut because the best oaks were retained and 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 management (Brose and others 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 and others 1999b). Many upland game and nongame species utilize the mast, browse, and cover in a regenerating shelterwood (Brose and others 1999b, Lanham and others 2000).

The shelterwood-burn method could be used to restore rare fire-maintained ecosystems (Brose and others 1999b). Frequent (1-2 year intervals) growing season burns after the initial shelterwood cut would favor herbaceous vegetation (Bond and van Wilgen 1996) and would gradually reduce the density and size of woody regeneration and create a hardwood woodland or savannah, two increasingly rare habitats in the eastern United States after decades of fire exclusion (Buckner 1983, Pyne 1982, Van Lear and Waldrop 1989, Abrams 1992).

Would a regeneration technique developed in the Piedmont of Virginia be successful in the Central Hardwood Region? Some fire research suggests that it would. 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 regeneration (Arthur and others 1998). Hot fires in mountain laurel thickets in the Northeastern United States opened overstory canopies, i.e., a disturbance similar to a shelterwood harvest, and allowed oak reproduction to grow past the dense shrub layer (Moser and others 1996).

FELL AND BURN SITE PREPARATION FOLLOWING COMMERCIAL CLEARCUTTING

Phillips and Abercrombie (1987) described a site preparation technique used in the Southern Appalachians following commercial clearcutting (removal of merchantable stems only) to develop pine-hardwood mixtures. The technique consisted of spring felling of residual (unmerchantable) stems after leaf-out, followed by an intense, but not severe, summer broadcast burn. Pine species were then planted at relatively wide spacings to maintain a pine component among the sprouting hardwoods.

Spring felling of residuals followed by burning reduced sprout growth of competing hardwood species more than that of oak sprouts. The intense broadcast burns used in this technique often cause new oak sprouts to originate from below the mineral soil surface and result in well-anchored stems. These results indicate that intense broadcast burns following harvest should increase (or at least maintain) the oak component in the new stand.

Care must be used in prescribing broadcast burns on poor quality sites. If the burns consume the entire forest floor, severe erosion and nutrient loss may result. These negative consequences can generally be prevented if burning is done when the lower layers of the forest floor and root mat are damp. Such conditions often occur in the Southern Appalachians a few days after a soaking rain (Phillips and Abercrombie 1987).

CONCLUSIONS

Until the early decades of the past century, fire played a major role in maintaining oak-dominated forests in the eastern United States. As a result of fire exclusion and, in some cases, other factors, such as deer browsing, oak forests on good quality sites are being replaced by other species. On poor quality sites oaks are maintaining themselves.

Upland oaks are well adapted to regimes of frequent low-intensity surface fires. Because of these adaptations, prescribed fire can be used to accomplish different management objectives, ranging from establishment of oak regeneration to restoration of open oak woodlands. However, foresters have been reluctant to use prescribed fire in hardwood stands because of fear of damaging boles of high-value trees.

Practical silvicultural prescriptions using fire for oak regeneration have been lacking. It is now understood that periodic understory burning in mature mixed hardwood stands creates environmental conditions, such as reduced low shading and less competition, which favor oak regeneration. In addition, a shelterwood-burn method has recently been developed for good quality sites which have proven successful in improving oaks' competitive position in the advance regeneration pool in mixed hardwood stands. This technique reduces the density and vigor of oaks' competitors, especially when growing season burns of relatively high intensity are used, and develops adequate numbers of vigorous free-to-grow oak stems in the advance regeneration pool.

Forest managers will need to use prescribed fire or a fire surrogate (herbicide) to sustain oaks on good quality sites. The land-use history of the Central Hardwood Region and the fire ecology of oaks tell us that fire and oak forests go hand in hand. If we study our history (as recorded both by man and by nature) carefully, we will understand that the region has been a managed landscape for millennia and fire was the primary management tool. It played a major role in sustaining oak forests and will need to be used now and in the future to favor oaks.

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