# RESPONSES OF OAK AND OTHER HARDWOOD REGENERATION TO PRESCRIBED FIRE: WHAT WE KNOW AS OF 2005

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**Abstract**.—An obstacle to using prescribed fire to manage mixed oak forests is the varied results of previous fire studies. It has been reported that fires enhanced, hindered, or had no effect on the competitive position of oak in the regeneration pool. We review a portion of the published literature and identify key factors that led to the relative competitiveness of oak reproduction benefiting from or being harmed by prescribed fires. These key factors are synthesized into general guidelines to help practitioners understand how fire can be a positive force in the oak regeneration process. We also point out some situations where fire hinders the competitive position of the oak regeneration, and provide suggestions for researchers studying fire in mixed oak forests.

## INTRODUCTION

There is developing consensus that fire has had a close association with and has shaped the species composition of mixed-oak forests in the eastern United States for the last several thousand years (Crow 1988; Abrams 1992; Brose and others 2001). Scars on stem cross sections are evidence that prior to the fire control era that began in the 1920s, fires in Ohio, Maryland, and West Virginia occurred at intervals of 5 to 15 years during the previous four centuries (Sutherland 1997; Shumway and others 2001; Schuler and McClain 2003). Other fire-scar studies have documented fire return intervals ranging from 2 to 24 years from New Jersey to the western portion of the mixed-oak forest in Missouri (Buell 1953; Dey and others 2004). Evidence of reoccurring fire also predates European contact in the eastern United States. In a charcoal and pollen accumulation study in the southern Appalachians, Delcourt and Delcourt (1997) found evidence of landscape-level fires in a forest dominated by oak, American chestnut, and pine throughout the past 3900 years.

The heretofore unrecognized close association of fire and oak forests in the eastern United States has led researchers to investigate the use of prescribed fire to sustain and regenerate oak forests. Eastern fire studies cover a wide range of stand characteristics, species mixes, fire intensities, associated silvicultural practices, and number of fires, and include an equally wide range of results. The competitive position of oak reproduction in the regeneration pool can be enhanced or hindered or not be affected. In this paper we review a portion of the fire/oak literature, grouping studies during the past four decades by stand structure (fully stocked mature and less than fully stocked mature), fire intensity (low and high), number of burns (single, twice, three to five, and six or more), and response of oak regeneration. We synthesize the common denominators for when the competitive position of oak reproduction is enhanced or harmed by prescribed fire and provide guidelines on using fire to help regenerate mixed oak forests.

## Single Fires

### Mature Stand, Low-Intensity Fire

This is by far the most common stand and fire type in the literature (Fig. 1). In this group, mature stands are in the understory reinitiation stage of development (Oliver and Larson 1996), usually are at least 75 years old and are near the end of a typical timber rotation for oak sawlogs. Low-intensity fires are defined as those with flames less than 2-feet long, which consume only the leaf litter and small woody debris, and cause little, if any, overstory mortality. The effect of these fires in this setting may be beneficial, detrimental, or neutral with respect to the relative competitiveness of oak regeneration (Fig. 1). American beech (*Fagus grandifolia*) remained the dominant species after a light surface fire in New York (Swan 1970). Nyland and others (1982) reported that the dense understory that develops after a single fire in New York could inhibit oak regeneration.

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In a study of the same burns, McGee and others (1995) found that the single fire increased the competitive status of American beech and red maple (*Acer rubrum*) while reducing the importance value of northern red oak (*Quercus rubra*). Prescribed fire reduced northern red oak survival and did not increase basal diameter growth in northern Georgia (Loftis 1990a). Low-intensity fires increased red maple and black birch (*Betula lenta*) density relative to oak in Connecticut (Ducey and others 1996). In this study there was no difference in height growth of oaks between the low-intensity and unburned sections (Moser and others 1996).

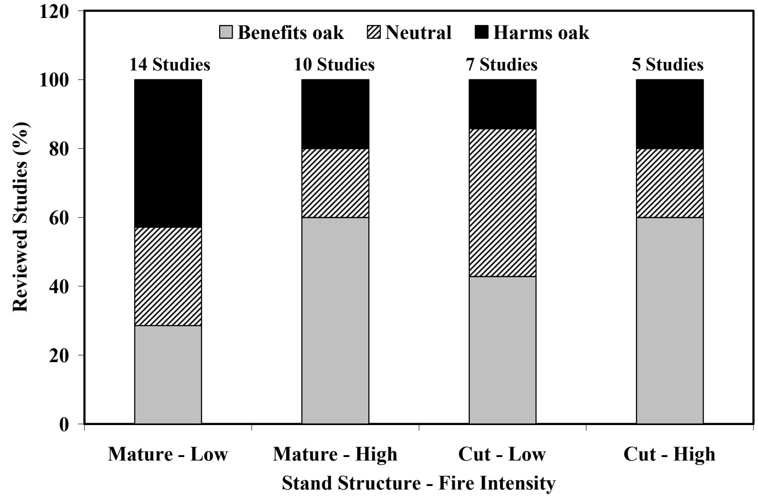


Figure 1.—Distribution of reviewed studies of the response of hardwood regeneration to single fires. The studies were divided into 12 groups based on stand structure, i.e., had the overstory been harvested to some degree, reported fire intensity (flame length or overstory mortality), and whether the fire benefited, harmed, or did not affect the competitive position of oak in the regeneration pool.

One of the more widely reported studies is the National Fire and Fire Surrogates project in southern Ohio. Low-intensity fires in unmanaged stands did not increase the number of oak seedlings after 1 year (Iverson and others 2004) or 2 years (Apsley and McCarthy 2004). In an associated study, McQuattie and others (2004) found that burning had no significant effect on seedling height of black oak (*Q. velutina*) and red maple. However, in this study, seedlings of both species were more massive on burned than unburned plots. A later report of the same study found that red maple seedlings, but not those of chestnut oak (*Q. prinus*), were taller in burned than unburned sections 2 years after the burn (Apsley and McCarthy 2004). In a related study also in southern Ohio, Hutchinson and Sutherland (2000) reported that red maple and white oak seedling frequencies were unchanged 3 years after a light surface fire. The effect of low-intensity fire on comparative height growth was equally ambiguous.

Several studies of low-intensity fire in mature stands have reported beneficial effects on oak regeneration. Barnes and Van Lear (1998) found that 2 years after a low-intensity spring fire in the southern Appalachians, regeneration (less than 2.0 inches in d.b.h.) densities of oak, hickory (*Carya* spp.), and sourwood (*Oxydendrum arboreum*) increased, while red maple density decreased. This change in species composition resulted in a slight increase in relative density of oak regeneration from 31 percent before the prescribed burn to 37 percent 2 years later. In Kentucky, Adams and Rieske (2001) found that the seedling height and diameter growth of white oak (*Q. alba*) was enhanced by a prescribed burn. A separate study on Kentucky ridgetops reported increases in density of both oak and red maple seedling densities after prescribed fire (Kuddes-Fischer and Arthur 2002). A low-intensity fire in south-central New Jersey resulted in low mortality of small oaks (Little 1946).

## Mature Stand, High-Intensity Fire

In this category, high-intensity fires are defined as those with flames longer than 2 feet or killing significant numbers of overstory trees. Studies reporting on this type of fire in mature stands are less common than for the previous group (Fig. 1). Generally, these fires enhanced the competitive status of oak regeneration. Several of the researchers examined the aftereffect of wildfires by comparing burned areas and adjacent unburned stands. In New York, high-intensity fires did not change the average frequency of black oak but reduced the average frequency of red maple and white oak (Swan 1970). Swan also reported that the percentage of oaks top-killed by the fire was lower than that for red maple, sugar maple (*Acer saccharum*), and American beech.

Both absolute and relative densities of oak were increased 7 years after a high-intensity prescribed fire in North

Carolina (Maslen 1989). Although survival of oaks within a given size class was higher than for non-oak species following the fire, height growth was greater for non-oak than for oak species. Another North Carolina study reported that the density of scarlet (*Quercus coccinea*) and chestnut oak increased 1 year after a high-intensity fire while the density of red maple, northern red oak, and white oak decreased (Elliott and others 1999). In Connecticut, Ducey and others (1996) reported the density of northern red oak, eastern white pine (*Pinus strobus*), and black birch was higher 7 years after a high-intensity prescribed burn than on unburned plots while the density of red maple and white oak was decreased by the fire. As a follow-up to the Ducey paper, Moser and others (1996) reported that the height growth of oaks was greater following the high-intensity fire than that of oaks in the unburned controls.

Perhaps the primary reason for the increase in survival and growth of seedlings after high-intensity fires is that the amount of light reaching regeneration following fire-induced mortality of overstory trees was increased. Loftis (1990b) reported that the survival of northern red oak seedlings increased following a reduction in overstory density (similar to a high-intensity fire) as opposed to a reduction in understory density (similar to a low-intensity fire).

High-intensity fires are not a panacea for regenerating oaks. In addition to the resulting economic loss of timber (Hepting 1941; Little 1946; Paulsell 1957; Loomis 1973; Ward and Stephens 1989), high-intensity fires may inhibit the development of oak regeneration relative to other species. In West Virginia, the density of northern red and chestnut oak advanced regeneration decreased 5 years after a fire that reduced overstory basal area by 17 percent (Wendel and Smith 1986). In contrast, red maple density increased slightly over the same period.

### Cut Stand, Low Intensity Fire

This stand type differs from the mature type in that cutting by group selection, shelterwood, clearcut, etc preceded the fire by one or more years and the regeneration layer was developing into saplings, i.e., the stand initiation stage (Oliver and Larson 1996). There were fewer studies of fire for this stand than for mature stands (Fig. 1).

In West Virginia, Collins and Carson (2003) reported that prescribed burning of recently created gaps reduced the abundance of northern red oak while the density of competitors was increased or not affected. Dolan and Parker (2004) found that a combination of burning and thinning did not result in the establishment of new oak seedlings on mesic or xeric oak sites in Indiana, but did result in greater consistency with respect to the number of shade-tolerant and intolerant seedlings in the understory. Jackson and Buckley (2004) noted an increase in small oak seedlings but attributed this to the sprouting of large oak seedlings that had been top-killed by fire a year earlier.

Fire studies in cut stands with a longer interval between the harvest and fire have shown substantial benefits to the oak regeneration. Brose and Van Lear (1998) and Brose and others (1999a) reported increases in the relative dominance of oak when burning was done 4 years after a heavy shelterwood cut. Kruger and Reich (1997) reported comparable results from fires conducted in 4-year-old oak shelterwoods in Wisconsin. In Connecticut, burning several years after a heavy shelterwood cut or a complete overstory removal also has increased the competitive position of oak in the regeneration pool (Ward and Gluck 1999; Ward and Brose 2004).

### Cut Stand, High Intensity Fire

This grouping of papers was the smallest (Fig. 1) but included the oldest fire study in the eastern United States. A high-intensity fire in 1932 topkilled half of the stems less than 6 inches d.b.h. in a 30-year-old sapling stand in Connecticut. Fifty-five years after that fire, Ward and Stephens (1989) reported that oak densities were twice as high in burned than in unburned areas. The fire had no long-term effect on the density of other species groups. Comparable results were reported for Rhode Island (Brown 1960).

One of the first attempts to use fire along with a partial reduction in overstory stocking to increase the importance of oak in the understory was by Wendel and Smith (1986) in the Ridge and Valley region of eastern West Virginia. The effects of the fire were evaluated on the overstory and understory. Two years before the fire, the stand was thinned from below, e.g., the undesirable trees less than 6 inches d.b.h. plus cull trees were felled and left on the site. Strip head fires in the spring of 1980 consumed about 56 percent of the litter fuels and 18 percent of the woody fuels. Fire intensity varied with strip width, fuel loading, and wind patterns, though it likely was increased by the addition of fuels from the thinning 2 years earlier. Average fire scar height was about 5 feet, indicating a high-intensity fire for hardwood leaf litter. The fire reduced the number of stems more than 5 inches d.b.h. from 115 to 93 per acre and reduced basal area from 90 to 73 feet/acre. In the understory, red maple and black locust seedlings and sprouts increased in number while the number of northern red and chestnut oak decreased.

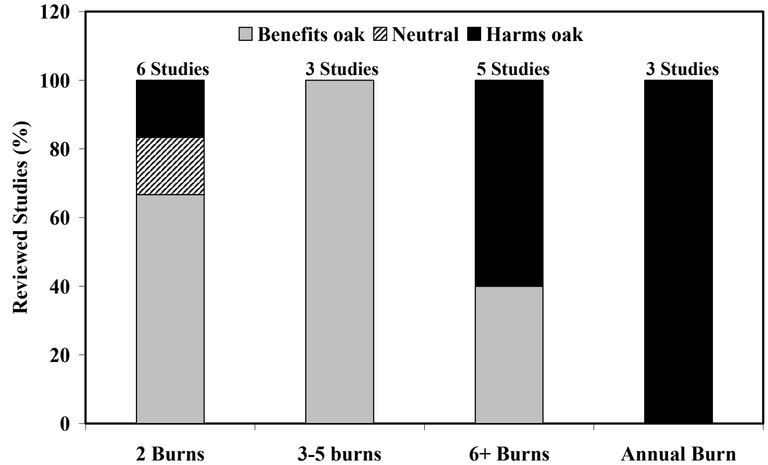


Figure 2.—Distribution of reviewed studies of the response of hardwood regeneration to multiple fires. The studies were divided into 12 groups based on the number of periodic burns and whether the fire benefited, harmed, or did not affect the competitive position of oak in the regeneration pool.

In a fire study conducted in the Virginia Piedmont, Brose and Van Lear (1998) and Brose and others (1999a) found that high-intensity fire was especially beneficial to the relative competitiveness of oak regeneration if the fire occurred during the spring versus summer or winter. High-fire intensity also was more beneficial to oak than low-intensity fire in studies by Ward and Gluck (1999) and Ward and Brose (2004).

## Multiple Fires

Multiple prescribed burns at interval of 2 to 3 years were suggested by Sander (1988) to control unwanted woody competition. However, the impact of multiple burns may vary by the number of burns and their frequency (Fig. 2). Some researchers reported that periodic burns increase the competitive status of oak regeneration. A prescribed fire in Kentucky followed 2 years later by a wildfire increased the number of oaks in the shrub stratum (20 inches tall to 1 inch d.b.h.) more than six fold (Arthur and others 1998). This combination of fires also doubled the number of red maple in the shrub stratum versus the unburned plots. However, the plots that had been burned only once had higher red maple densities than the plots that had been burned twice. The second fire reduced the density of red maple sprouts and increased the number of chestnut oak sprouts.

In New York, both the relative and absolute densities of northern red oak reproduction more than 4.5 feet were greater on plots that had burned twice than on plots that had been burned once in New York (McGee and others 1995). This study also reported that northern red oak densities were higher following two high-intensity than two low-intensity fires and that the two hot burns increased the competitive status of American beech. Periodic burns at intervals of 5 years or less have nearly eliminated red maple from red pine (*Pinus resinosa*) stands in Michigan (Henning and Dickmann 1996).

Barnes and Van Lear (1998) reported that after three winter burns in South Carolina, there were fewer oaks than after a single spring fire. However, the winter-burned stands contained more than 5,000 stems/acre of oak regeneration and the height of oak sprouts following three burns was more than twice that of sprouts after a single spring burn. Following three periodic prescribed fires in Tennessee, oak regeneration was abundant, averaging more than 1,500 stems/acre (Clatterbuck 1998). Basal diameter and relative height growth of white oak seedlings were increased by two prescribed burns in Kentucky (Adams and Rieske 2001). However, relative height growth was greatest for seedlings in plots burned only once.

Other researchers maintain that periodic burning should be used with caution if the management objective is to regenerate oak. In a study in Tennessee, Thor and Nichols (1973) found that two periodic burns separated by 5 years increased the density of oak, sumac (*Rhus* spp.), and sassafras (*Sassafras albidum*) regeneration and eliminated red maple reproduction. However on the same plots, four additional periodic burns at intervals of 4 to 5 years the same plots increased the absolute and relative densities of red maple (DeSelm and others 1991). Concurrently, the density of post (*Q. stellata*), scarlet, and southern red oak (*Q. falcata*) decreased. In Missouri, periodic burning reduced the density of small oak saplings (Sasseen and Muzika 2004) while oak mortality increased with burning frequency (Dey and Hartmann 2004). For example, a single fire only resulted in 10-percent mortality among black oaks with a basal diameter of 1 inch, but three or more fires killed 25 percent of stems. In New Jersey, the mortality of oak saplings (one inch d.b.h) increased as the intervals between fires decreased. Mortality was 100 percent on annually burned plots, 62 percent on plots burned at 3-year intervals, and 11 percent mortality on plots burned at intervals of 10 years or longer (Somes and Moorhead 1950). In Kentucky, Green and others (2004) reported that red maple seedlings were tallest on plots burned three times than on those burned twice or not at all. They also noted that oak seedlings were tallest on unburned plots. Although red maple seedlings were taller than oak seedlings, mortality was higher in red maple.

In most studies researchers reported that annual burning reduces all regeneration density, including oak seedlings and saplings (Little and Moore 1949; Chaiken 1952; Paulsell 1957; Grano 1970). Although 6 years of annual burning in Tennessee increased total regeneration density and the density of oak regeneration (Thor and Nichols 1973), an additional 21 years of annual burns on these same plots eliminated all regeneration except for winged sumac (*R. copallina*) and oak (DeSelm and others 1991). Although some oak remain (primarily post oak) total density has declined by 97 percent or more. In the Missouri Ozarks, four annual burns greatly reduced or, in one case, eliminated small oak saplings less than 1.5 inches d.b.h. (Sasseen and Muzika 2004) and 14 years of annual burning eliminated large sapling stems in Minnesota (White 1983). The frequency of red maple seedling decreased after three annual burns in southern Ohio (Hutchinson and Sutherland 2000); surprisingly the frequency of white oak seedlings was not changed by the annual burns.

## Synthesis

Every possible response of oak regeneration to fire is found in the literature, though commonalities among studies are apparent when the competitive position of the oak reproduction is enhanced or hindered. Results were most varied for single, low-intensity prescribed fires in mature stands. Where oak regeneration was harmed in this setting (Loftis 1990a; Nyland 1982; McGee and others 1995; Moser and others 1996), the studies were conducted on high-quality sites. The oak stems were small and they had been growing in dense shade. These stems probably had small root systems and minimal root carbohydrate reserves, and likely were of low vigor at the time of the fire. Several researchers have reported that such stems, regardless of species, usually do not survive fire of any intensity (Johnson 1974; Loftis 1990a; Brose and Van Lear 2004). Also, the fires did not significantly increase the amount of sunlight reaching the forest floor, so oak stems sprouting after the fires were forced to grow new tissue in sub optimal light conditions.

When single low-intensity surface fires benefited oak regeneration in mature stands (Little 1946; Barnes and Van Lear 1998; Adams and Rieske 2001; Kuddes-Fischer and Arthur 2002), the studies were conducted on dry, hot, sandy soils or xeric upper slopes. Oak regeneration tends to accumulate on such sites because they have sparser canopy cover and more sunlight reaches the forest floor (Johnson and others 2002). Thus, the regeneration has larger root systems and greater root carbohydrate reserves, and is more vigorous. Brose and Van Lear (2004) found that such oak regeneration generally sprouts after a low-intensity fire.

Single low-intensity fires in cut stands also produced varied results. The major differences between studies reporting a positive effect on oak regeneration and those reporting no effect or a negative impact were related to the intensity of cutting and the length of time between the cutting and the fire. The positive studies (Kruger and Reich 1997; Brose and Van Lear 1998; Ward and Gluck 1999; Ward and Brose 2004) were conducted in heavily cut shelterwoods or clearcuts and at least 4 years had passed between the cutting and the fires. In the neutral and negative studies (Collins and Carson 2003; Dolan and Parker 2004; Jackson and Buckley 2004), the degree of cutting was much lighter e.g., small gaps and low thinning, and only 1 or 2 years elapsed between the cutting and the fire. There is a clear relationship among the amount of light, number of growing seasons, and size/vigor of oak seedlings (Miller and others 2004). In the positive studies, the oak reproduction at the time of the cutting had sufficient light and time to build large root systems so it was more likely to sprout after the fires. In the neutral and negative studies, the regeneration reacted like small, low-vigor seedlings experiencing fire in a mature stand: it died or responded poorly.

The high-intensity fires in mature and cut stands generally benefited oak by being more detrimental to the survival and growth of non-oak species than to the oaks. This disparity is attributed to inherent differences in germination strategy between oaks and many of their competitors. Acorns have hypogeal germination, i.e., cotyledons remain in the shell and serve as a below-ground energy source for seedling development. Seeds of common competitors, e.g., red maple, have epigeal germination, i.e., cotyledons emerge and rise above the shell to form the first photosynthetic leaves. This difference in germination strategy places oak seedlings' root collar, and the accompanying dormant buds, lower than that of red maple. This difference in germination strategy is accentuated by wildlife. Acorns are routinely buried an inch or more into the forest floor by birds and small mammals while seeds from red maple and other competitors typically are not cached. Thus, an oak seedling generally has a deeper root collar than a red maple seedling due to seed burial and hypogeal germination. Consequently, hotter fires are more likely to kill the dormant buds of red maple than those of oak.

Another important silvical difference between oak regeneration and the reproduction of many competitors is the developmental rate of the root system. Upon germinating, oaks send a strong radicle deep into the soil to establish a taproot and emphasize root development over stem growth (Kelty 1988; Kolb and others 1990). Most competitors take the opposite approach; root development is sacrificed to promote rapid stem growth. Thus, oak regeneration usually has shorter stems than those of the competition but has larger root systems. Because of these silvical characteristics – hypogeal germination, emphasis on root development, and seed burial by wildlife – oak regeneration is less detrimentally affected by high intensity fires than its competitors.

The adverse effect of high-intensity fire on oak regeneration in previously cut stands (Wendel and Smith 1986) likely was caused by the short interval between cutting and the fire. Also, a high deer population may have preferentially browsed oak sprouts more than those of competitors during the 5 years between the fires and data collection.

Generally, two to five fires spread over a decade or more have benefited the competitive position of oak in the regeneration pool, likely due to selecting against species with inherently smaller root systems and creating/maintaining an understory light regime more favorable to the development of oak rootstocks. Multiple periodic burns may be a reasonable mimic of single, high-intensity fires in that they both create more open understories (but at different time scales).

However, multiple periodic fires do not always benefit oak. Merritt and Pope (1991) compared single burns conducted in the fall with a second burn conducted in the spring two growing seasons later. Consistent with other studies, both the first and second prescribed fires significantly reduced the number of competing shade-tolerant saplings 10 to 20 feet tall; however, neither the first or second prescribed burn aided in the establishment of new oak seedlings. Merritt and Pope concluded that it was not advisable to use fire alone, including multiple fires, to aid in the establishment of new oak seedlings in stands described as "recently mature."

Although the root mass/size of oak regeneration dwarfs that of most competitors of similar-size, it can be exhausted by multiple resprouting. This is evident in studies in which multiple periodic fires or annual burning were examined. There seems to be a point at which repeated fire does not continue to benefit the oak component of the regeneration pool. Where that point is and how rapidly it is reached likely is a function of several stand characteristics.

None of the reviewed fire/oak papers focused exclusively on oak and all contained information on other eastern species. From these papers, species can be grouped into three broad classes: susceptible, intermediate, and resistant to fire. Susceptible species, which are poor sprouters following fire, include black birch, eastern hemlock (*Tsuga canadensis*), eastern white pine (*P. strobus*), hophornbeam (*Ostrya virginiana*), sugar maple, and yellow-poplar (Marquis 1975; Kruger and Reich 1997; Brose and Van Lear 1998; Ward and Brose 2004). Fire-resistant species include the oaks, sympatric species such as the hickories (*Carya* spp), and those capable of consistent root sprouting e.g., aspen (*Populus* spp.), black locust *(Robinia pseudoacacia*), and sassafras, as long as there is sufficient light for sprouts to survive (Kruger and Reich 1997; Brose and Van Lear 1998; Waldrop and Brose 1999). Intermediate species differ from resistant species in how their sprouting ability responds to changes in fire intensity, fire seasonality, and seedling size. This is particularly true of red maple (Huddle and Pallardy 1996, 1999). Small red maple is readily killed by fire, even low intensity burns (Reich and others 1990) but the sprouting ability of this species develops as size increases (Brose and Van Lear 2004; Ward and Brose 2004). In most dormant-season burns and low-intensity fires, large advance red maple regeneration equals that of oaks in sprouting ability (Brose and Van Lear 1998). However, red maple is a markedly poor sprouter as fire intensity increases, especially during the growing season. Other intermediates that exhibit a wide range of root sprouting ability include American beech, blackgum (*Nyssa sylvatica*), and pin cherry (*Prunus pensylvanica*).

## Guidelines for Foresters and Researchers

The following guidelines can aid foresters who plan to use fire to regenerate oak forests:

1. Prescribed fire is best used after significant reductions in overstory stocking to release existing oak seedlings, sometimes referred to as advanced regeneration, from competition. Prescribed fires should occur after released oak seedlings have had time to develop robust root systems (root collar diameter > 0.75 inch) that can sprout vigorously. The recommended time is 3 to 5 years after a shelterwood harvest that reduces stocking by about 50 percent in a fully stocked stand (Brose and others 1999a, b). Measures to protect valuable residual trees likely will be needed (Brose and Van Lear 1999).

2. Prescribed fires in late spring or summer are the most lethal to oak competitors because their root reserves are at their lowest levels. In some locations, the window of opportunity for such burns may be too short for planning purposes, so the focus should be on spring burns just before or during leaf expansion.

3. In the absence of adequate numbers of existing oak seedlings, the use of fire to establish new oak seedlings generally has not been successful. Some factors related to understories with inadequate densities of advanced oak regeneration are not related to the fire and oak relationship. Fire can create conditions suitable for oak establishment by reducing litter layers and reducing understory and midstory competition, but in the absence of large acorn crops, the newly available growing space will be used by other species in 1 to 2 years. Seedling establishment is largely dependent on large acorn crops that can overwhelm seed and seedling consumers, for example insects, rodents, and white-tailed deer. Avoid burning when an acorn crop has just occurred (Auchmoody and Smith 1993) or when oak seedlings are small, of low vigor, or recently established (Loftis 1990a; Brose and Van Lear 2003).

4. The use of fire following clearcuts has produced encouraging results in some locations. When oaks are present in the regeneration but other species are at much higher densities, a moderately intense prescribed fire can increase the relative density of oak by taking advantage

of this species' superior sprouting characteristics. Like shelterwood harvests, prescribed fires after clearcuts should be scheduled to allow oaks time to develop robust root systems that can produce vigorous sprouts. The time needed may be less than the 3 to 5 years recommended for the shelterwood regeneration process, but allow sufficient time for seeds of other species to germinate. Fires in clearcuts do not injure valuable residual trees unless some are retained for other management objectives.

5. Deer browsing is important in many areas and must be addressed should densities exceed a critical threshold before the regeneration process. High deer densities drive forest succession and discriminate against sprouting oaks after a fire (Collins and Carson 2003; Horsley and others 2003). This is an added obstacle on productive mesic sites where competition from non-oaks is greatest. In such cases, the use of fencing or other drastic means is necessary to mitigate the impact of deer.

6. A successful oak regeneration plan likely will ensure a diversity of woody species in the new stand. None of the silvicultural studies we reviewed reported the elimination of common oak competitors though many documented the virtual loss of oak when the regeneration plan favors other species intentionally or unintentionally.

The following are reminders concerning the essentials of high-quality research as well as points to consider in conducting fire research in oak forests:

1. Classify or measure fire intensity and/or severity at the same scale used to monitor regeneration response. This was by far the most common shortcoming in the studies we reviewed. The authors of several early fire/oak papers did not describe fire behavior while others included only general descriptions (cool, hot) at the stand level. Fortunately in more recent papers, fire behavior is described in more appropriate terms, for example, flame length, rate of spread, and char height, to help the reader gain a mental picture of the fire. The best papers report fire behavior and fuel consumption at the same scale that responses are measured.

2. Document preburn forest conditions. The response of a plant community to fire is influenced by several preexisting factors, especially the size/vigor of the regeneration and understory light levels. The more the preburn conditions are documented, the more useful the study. For oak reproduction this almost always requires measuring the diameter of the root collar

3. Use a control treatment. This should seem obvious, but, we reviewed studies that did not include unburned controls. Statistical inference, subsequent publication, and value to the scientific community of fire studies will be greatly enhanced with a control.

4. Do not be hasty in reporting results. Fire effects may take three years or more to be fully manifested. Early results need to be reported as preliminary rather than as definitive.

5. Publication of fire/oak studies need to be in high-quality journals so they reach the scientific community and technical outlets for the practicing forester.

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