TIMING FIRE TO MINIMIZE DAMAGE IN MANAGING OAK ECOSYSTEMS

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Abstract--The long history of fire in North America spans millennia and is recognized as an important driver in the widespread and long-term dominance of oak species. Early European settlers intensified the occurrence of fire from about 1850 to 1950, with dates varying by region. This resulted in much forest damage and gained fire a negative reputation. The lack of fire for the past 50 years due to suppression programs is now indicted as a major cause of widespread oak regeneration failures. Alarms are sounding for the continued loss of oak forests. The use of prescribed fire is increasing in forest management and ecosystem restoration. An understanding of fire effects on trees can provide the basis for the silviculture of restoring and sustaining oak ecosystems. We present an overview of fire-tree wounding interactions, highlight important determinants of fire injury and damage, and discuss several practical situations where fire can be used to favor oak while minimizing damage and devaluation of the forest. We also identify stages in stand development, regeneration methods, and management objectives for which fire has the potential of causing substantial damage and alternative practices should be preferred.

INTRODUCTION

A major impetus for forming state and federal forestry agencies was to avert a national timber famine by instituting science-based forest management, halting timber theft, and stopping forest destruction due to frequent and catastrophic wildfires (Keefe 1987, Pyne 1982, Pyne and others 1996, Steen 1976). It was widely recognized that the high levels of decay and cull timber in eastern hardwood forests were due to a history of wildfires (Burns 1955, Gustafson 1944, Hepting 1937, Kaufert 1933). American Indians frequently lit fires for numerous reasons, and these fires burned unsuppressed over large landscapes before European immigration to North America (Guyette and others 2002, 2012a). European settlers initially adopted American Indian burning practices, increasing the frequency of fire and saturating the landscape with fire (Guyette and others 2002). Forest fires are capable of causing wounds at the base of tree boles, and wounds can become quite large with increasing fire intensity. These wounds provide entry points to wood-decaying fungi that can cause substantial loss of wood volume and value over time (Guyette and others 2012b; Hepting 1935, 1941; Hesterberg 1957; Loomis 1974; Stambaugh and Guyette 2008). The cumulative effects of a history of fire persist for decades in forests because trees are long-lived organisms. Therefore, it is not surprising that there is a trend of higher cull percent of live total net volume with increasing historic fire frequency in the eastern United States (fig. 1). The highest levels of live cull in standing timber today occur in the Southern, Great Plains Border, and former Prairie Peninsula regions where fires were historically more frequent. Great Plains Border states commonly experience seasonal drought and cyclical periods (e.g., 21 to 22 years) of severe drought (Stambaugh and Guyette 2004) that promote higher-intensity fires and more severe tree wounding. Also, woods burning in the South and hill country of the Midwest persisted longer than in other regions of the eastern United States due to cultural differences (Pyne 1982).

Foresters have been working hard for the past 75 years or so to suppress wildfires and get private landowners to stop indiscriminate woods burning. Their efforts have been highly successful. For example, about 2,500 human-caused wildfires burn annually in Missouri, but the average fire size is 10 acres due to fire suppression (Westin 1992). Consequently, the percent of cull live timber in Missouri has decreased from about 50 to 18 percent since the 1950s (Burns 1955, Miles 2013). In the past 10 to 30 years, prescribed burning to restore oak/pine (*Quercus* spp./*Pinus* spp.) savannas and woodlands has increased on public lands, especially in the Great Plains Border Region.

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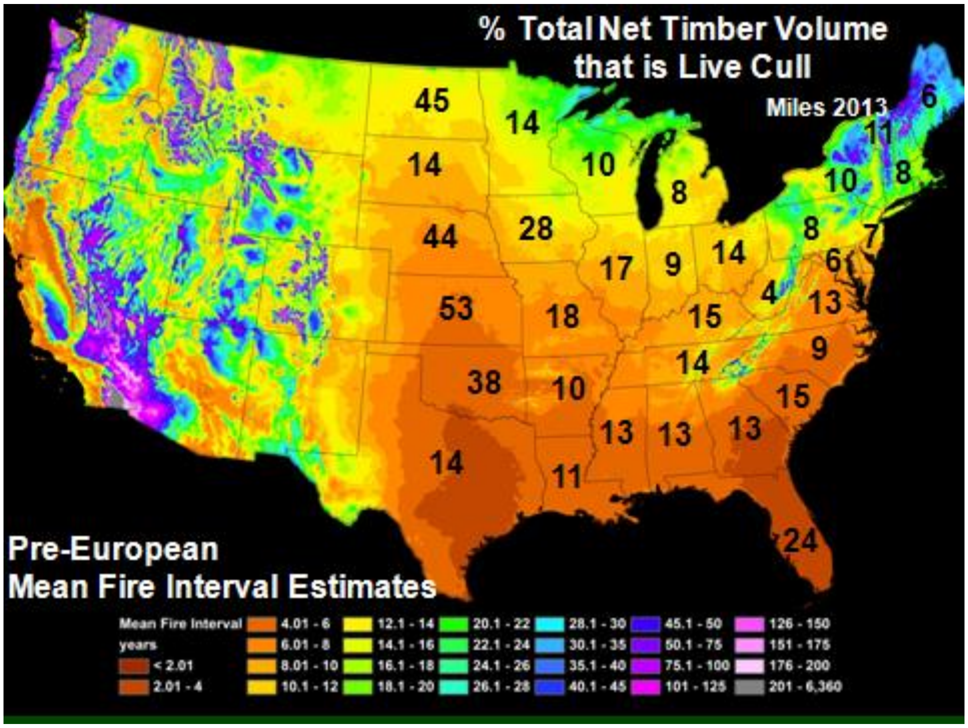

Figure 1--Estimated mean fire interval for low-intensity fires before European settlement circa 1650-1850 (Guyette and others 2012) and percent of total net timber volume that is live cull in modern times according to a national forest inventory (Miles 2013).

For example, the Mark Twain National Forest Plan (MTNF 2005) calls for restoration of woodlands and savannas on 438,000 acres or 29 percent of the MTNF. In addition to these efforts, other federal and state agencies, The Nature Conservancy, National Wild Turkey Federation, and other NGOs are using prescribed burning to restore thousands of acres of woodlands and savannas throughout Missouri.

Efforts to restore native communities on this large-scale followed several decades of debate among resource professionals over the reintroduction of fire, especially in regions where it was a hard-won fight to get people to quit burning their woods. Improvements in timber quality and decreases in the amount of cull in forests following fire suppression were strong testimony to the benefits of keeping fire out of the woods. In this era of ecosystem restoration, using fire to restore native communities puts emphasis on ecological benefits such as increased native plant diversity and improved habitat quality for species that prefer woodlands and savannas. However, age-old concerns about fire damage to trees and forests remain.

The purpose of this paper is to provide a brief background on fire damage and the factors that influence damage in trees in the management of oak-dominated forests. Several management scenarios will be used to explore the appropriateness of fire at key stages in stand regeneration and development. Arthur and others (2012) provided an excellent synthesis of the role of fire in the life cycle of an oak forest with an emphasis on biology and ecology. We used a similar life cycle approach to select the scenarios for discussion. They are common stand conditions and developmental stages that are key break points in sustaining oak forests and woodlands.

TYPES OF FIRE INJURY AND DAMAGE

Tree Mortality

Surface fires in an eastern hardwood forest are capable of killing larger mature trees of any species if the intensity and duration of heating is sufficient to cause death of the cambium and foliage. Ground temperatures in low-intensity fires can be high enough to kill the tree cambium if the duration of heating is sufficiently long (Dey and Hartman 2005, Elliott and Vose 2005, Hutchinson and others 2005). However, thick bark is capable of protecting trees from complete girdling of the stem almost regardless of species (Guyette and Stambaugh 2004, Smith and Sutherland 1999). In mixed oak forests of the Central Hardwood Forest region, high percentages of overstory trees may be scarred on the lower bole from low-intensity fires but relatively small amounts of the overstory (e.g., < 5 percent basal area of trees > 4.5 inches d.b.h. or < 8 percent of stem density of trees > 16 feet tall) are lost to mortality from single or repeated low-intensity fires (Dey and Fan 2009, Hutchinson and others 2005, Regelbrugge and Smith 1994, Smith and Sutherland 2006). Higher fire intensity or longer exposure to fire is needed to kill larger (e.g., > 10 inches d.b.h.) trees, and this may occur locally during low-intensity fires where accumulations of litter, debris, or downed tree tops occur next to the base of individual large trees. Wildfires can cause stand replacement when they burn under severe fire weather, which is more likely to occur in years of severe drought.

Bole Wounding and Wood Decay

Prescribed fires, even of low intensity, can cause wounds to overstory tree stems, though not all trees are wounded, even when their bark may be charred (Smith and Sutherland 1999). Whether a tree is wounded or not depends largely on fire behavior (i.e., temperature, flame length, and duration of heating) at any one location within the burn unit, and bark characteristics of the tree (i.e., thickness, texture and heat conduction properties). Fire scars provide opportunities for wood-decaying fungi to colonize and infect tree stems. Large scars with exposed wood that remain open and moist for long periods provide good environments for fungal colonization and development. However, fire scars are often small and the bark commonly remains intact, covering the injury after low-intensity fires in upland oak forests of the Central Hardwood region (Smith and Sutherland 1999). Loss of volume and value in fire scarred oak trees may be relatively minor in the short-term (< 10 years), but with time, advanced decay can result in substantial value losses (Guyette and others 2012b, Stambaugh and Guyette 2008). Considering that about one-third of the total standing tree board-foot volume is in the butt 8-foot log, fire injury leading to wood decay at the base of a tree has significant potential effects on harvest volume and value. Even where timber production is not the primary management concern such as in woodland and savanna restoration, the longevity of mature overstory trees may be compromised by advance decay in the boles of fire-scarred trees because trees are more susceptible to stem breakage and blowdown during wind and ice storms (Guyette and Stambaugh 2004).

Stem Top-kill

Low-intensity fires are capable of causing death of the entire cambium on smaller diameter trees of any species. The bark of seedlings and saplings is relatively thin and offers less insulating protection to the cambium than mature, large diameter trees for any species (Hare 1965). Complete stem girdling results in the death of the shoot above the point of cambial injury. Many hardwood species are able to produce vegetative sprouts after one episode of top-kill (Dey and Hartman 2005, Regelbrugge and Smith 1994). Whether fire injury by top-kill is a benefit or considered damage depends on management objectives and the stage of stand development (Arthur and others 2012). Top-kill is a positive fire effect when used to favor the development of large and competitive oak reproduction by reducing the density of the mid- and overstory, or to increase the competitive status of oak regeneration by reducing the growth or density of competitors (Brose and others 2013). Repeated fires that cause mortality or top-kill of woody stems are desirable when trying to reduce stem density and forest cover in woodland and savanna restoration. In contrast, repeated top-kill of hardwood sprouts can adversely retard the recruitment of oaks and other desirable reproduction into the overstory, causing years of lost growth and delaying maturity.

DETERMINANTS OF FIRE INJURY AND DAMAGE

Trees can resist being injured by fire or they can minimize the damage following injury by defensive responses that confine damage (e.g., wood decay) to the area of initial injury.

Tree Species

Species-specific growth strategies and morphological characteristics result in different responses among species following fire, with oaks generally better-adapted to persist following burning than many competitors. The susceptibility to cambial death and top-kill by a single fire is nearly equal for seedlings and smaller sapling-sized stems, almost regardless of species. Mortality is high in the smallest of seedlings and new germinants, even in the oaks (Johnson 1974). However, large oak seedlings and saplings are better able to persist with repeated burning than their major competitors (Brose and others 2013). In general, oak species have a distinct advantage over competitors for surviving fire because they preferentially allocate carbohydrates to root growth and have an abundance of dormant buds commonly located in the soil where they are insulated from the heat of a fire (Brose and Van Lear 2004; Iverson and Hutchinson 2002; Iverson and others 2004, 2008; Johnson and others 2009). Nonetheless, oak stems < 4 inches d.b.h. are susceptible to top-kill, but the larger stems have a high capacity to persist by sprouting (Dey 1991), especially when there is adequate light for growth during the fire-free period. However, sprouting ability varies by species and begins to decline beyond a species-specific diameter threshold, which is usually in the pole-sized and small sawtimber size classes (Dey and others 1996, Johnson and others 2009). Lastly, species differences in ability to resist fire injury become more pronounced in the larger diameter size classes, and this has much to do with differences in bark characteristics (see below).

Tree Size

Size influences a tree's ability to sprout after fire-caused top-kill, as do the amount of root carbohydrate reserves and the presence of viable dormant vegetative buds after the fire (Dey and Hartman 2005). Low-intensity fires commonly cause top-kill of hardwood trees < 4 inches d.b.h. and a significant proportion of trees < 8 inches d.b.h. (Dey and Hartman 2005, Green and others 2010, Waldrop and others 1992). Guyette and Stambaugh (2004) found that post oak (*Q. stellata* Wangenh.) trees that were most likely to be scarred and survive a low-intensity dormant season fire were 4 to 8 inches d.b.h.; smaller trees were either top-killed or died. Larger seedlings and saplings of most hardwood species are able to sprout after top-kill caused by a single fire (Dey and Hartman 2005, Iverson and others 2008). For most species, sprouting capacity reaches a maximum with increasing diameter to a threshold size and then declines with further increases in diameter (Dey and others 1996, Johnson and others 2009). When large diameter oak trees in the overstory are girdled by fire, they are completely killed, being unable to produce sprouts. It is in the smaller size classes where oak trees are generally better able to persist after repeated fires than similar sized stems of their competitors (Brose and Van Lear 1998, Dey and Hartman 2005, Kruger and Reich 1997). Red maple (*Acer rubrum* L.) can be a troublesome species that competes with oak. If it is allowed to grow to sapling or pole-size, it becomes a persistent sprouter even after several low-intensity fires in the dormant season (Blankenship and Arthur 2006, Chiang and others 2005).

Bark Characteristics

There are many properties of a tree's bark that influence its ability to insulate the cambium from the heat of a fire: thickness, texture, thermal conductivity, specific heat, and thermal diffusivity. However, it is bark thickness that largely determines the degree of protection of the cambium from lethal temperatures (Vines 1968). As tree diameter increases so does bark thickness, and the degree of insulating protection increases exponentially with small increments in bark thickness (Hare 1965). Guyette and Stambaugh (2004) found that the probability of fire scarring and the percent of bole circumference scarred were significantly and negatively related to tree diameter, bark width, radial growth rate and tree age in post oak (d.b.h. range 4 to 28 inches). Sutherland and Smith (2000) reported that the probability of surviving a fire increases at the sapling size (2 to 4 inches d.b.h.) when the bark starts to achieve sufficient thickness to prevent top-kill, depending on species. Similarly, Guyette and Stambaugh (2004) observed that post oak trees > 4 inches d.b.h. were more likely to survive low-intensity fires without top-kill. There is however a substantial variation in bark thickness, rate of bark growth on the lower bole, and bark texture among species (Harmon 1984, Hengst and Dawson 1994, Sutherland and Smith 2000). Even with thick bark, scarring can occur in areas of bark fissures, creating a pattern of smaller injuries distributed around the circumference of the tree (Guyette and Stambaugh 2004).

In general, upland species have thicker bark than bottomland species for similar sized trees (Sutherland and Smith 2000). Bark thickness in white oak group species (*Quercus* Section *Quercus*) is the greatest followed by the red oak group species (*Quercus* Section *Lobatae*) in the Central Hardwood Forest region. Species with inherently thinner bark include American beech (*Fagus grandifolia* Ehrh.), flowering dogwood

(*Cornus florida* L.), black cherry (*Prunus serotina* Ehrh.), maple (*Acer* spp.), and hickory (*Carya* spp.). The rate of bark thickening during growth is important because faster growth rates allow trees to reach critical thresholds of thickness earlier that are associated with protection of the cambium and survival. Eastern cottonwood (*Populus deltoides* Bart. ex Marsh.) and yellow-poplar (*Liriodendron tulipifera* L.) are both thin-barked, fire-sensitive species when trees are small and young, but they have rapid rates of bark growth and are considered resistant to fire scarring as large mature trees. In contrast, silver maple (*A. saccharinum* L.) has a slow rate of bark growth all its life and is vulnerable to fire injury even when it is a large tree. Species that have smooth bark texture such as water oak are more vulnerable to fire injury to the cambium than are deeply fissured, rough textured species such as chestnut oak (*Q. prinus* L.) and bur oak (*Q. macrocarpa* Michx.).

Defense Against Decay

Diameter growth rate--determines how long a fire scar may provide entry of fungi into the tree's stem, once a wound is opened. In the event of an exposed fire scar, trees with faster rates of diameter growth are able to close the wound sooner, thus minimizing the time the wound face is available for fungal colonization. By sealing the wound, the tree also creates a less favorable environment for wood decay (Sutherland and Smith 2000). High rates of diameter growth more rapidly restore full vascular cambial functioning after fire scarring of the bole (Smith and Sutherland 2006). Growth near the area of injury (wound wood ribs) can be faster than on other portions of the bole (Smith and Sutherland 1999).

Compartmentalization--is a process whereby trees are able to establish a protective boundary surrounding cells injured by fire. The boundary is the result of the formation of tyloses and production of waxes, gums, and resins to form a barrier to further cell desiccation and microbial infection. The ability to compartmentalize injuries varies by species. The birches (*Betula* spp.) are less effective at compartmentalizing stem wounds than maples and oaks (Sutherland and Smith 2000). Oak species, especially those in the white oak group, have an unusual ability to rapidly compartmentalize fire injuries (Smith and Sutherland 1999, Sutherland and Smith 2000). Smith and Sutherland (1999) found that low-intensity dormant season fires produced relatively small scars (scorch height < 40 inches above the ground) that were often concealed by intact bark and were effectively and rapidly compartmentalized in black oak (*Q. velutina* Lam.) and chestnut oak trees (d.b.h. range 4 to 22 inches).

Decay resistance of the heartwood--varies by species and is important to retarding decay that originates from fire scarring. Species of the white oak group, black locust (*Robinia pseudoacacia* L.), catalpa (*Catalpa* spp.), black cherry, cedar (*Juniperus virginiana* L.), and cypress (*Taxodium* spp.) have heartwood that is resistant to very resistant to decay (Forest Products Laboratory 1967). Red oak group species, hickories, maples, sweetgum (*Liquidambar styraciflua* L.), yellow-poplar, birches, eastern cottonwood, and American beech have only slight to no resistance to heartwood decay.

Scar Size and Time Since Wounding

Fungi that infect tree boles through logging or fire scars can cause substantial loss of value and degrade in timber quality over several decades (Hesterberg 1957). Stambaugh and Guyette (2008) found that one third of the volume can be defect in white oak (*Q. alba* L.), black oak, and scarlet oak (*Q. coccinea* Muenchh.) butt logs within 25 years after the trees received a fire scar. The proportion of butt log that was defect after fire scarring increased with increasing size of fire scar (from 155 to 930 square inches) and decreased with increasing size of tree (from about 8 to 22 inches d.b.h.) at time of scarring. Loomis (1974) observed that the potential for volume and value loss from decay following fire scarring increased with diameter of tree at the time of scarring if the decay is allowed to progress for 2 or more decades. The rate and extent of heartwood decay depends on species, which vary in their heartwood resistance to decay (Forest Products Laboratory 1967).

Guyette and others (2012b) reported that both value and volume loss to decay and lumber degrade in black oak, northern red oak (*Q. rubra* L.), and scarlet oak butt logs increased with increasing prescribed fire severity and initial fire scar size as represented by scar height and scar depth. They reported that average scar height was 34 inches (range 6 to 154 inches) and scar depth was 2.6 inches (range 0.1 to 15 inches). Most of the devaluation in the butt log resulted from declines in lumber grade and not from volume loss. However, they found that percent scaled volume loss averaged only 4 percent, and value loss averaged 10 percent after 9 to 14 years since the fire. They concluded that where < 20 percent of the bole circumference was scarred and scar heights were < 20 inches that value loss would be insignificant within 15 years of scarring. Loomis (1974) confirmed that value and volume loss increased with increasing fire scar size (wound width and length), time since wounding, and tree diameter at the time of scarring. Similar evidence of the extent of fire injury was noted by Smith and Sutherland (1999) who measured scorch height on oak boles and found that it was generally < 40 inches after low-intensity prescribed fires in Ohio. They observed that most wounds occurred near the ground and were covered by intact bark, small in size, and rapidly and effectively compartmentalized within 2 years of the fire. Thus, losses due to wood decay can be minimized if fire intensity is low and scarred trees are harvested before decay becomes advanced.

The stage of stand development and tree size at the time of fire scarring may influence the probability that decay will substantially reduce wood volume or value by the time the tree is harvested. Fire scars on small diameter trees that survive the injury are necessarily small in size because they are limited by tree size. Closure of the wound is rapid if the tree is vigorous and free-to-grow; this minimizes the likelihood of fungal infection. Large diameter trees are better protected from fire scarring by their thick bark, and wounds tend to be small and low on the bole in low-intensity fires. These trees are merchantable and may be removed in a timber harvest soon after the fire, before any decay develops. Also, injuries generally occur on the large end of the butt log and therefore they are often outside of the scaling cylinder and do not effect product recovery and value. Fire-scarring of mid-sized trees that will remain in the stand for 30 years or more are most at risk of advanced decay development and significant loss of volume and value by the time they are harvested. Pole-sized and small sawtimber trees can sustain large-sized scars that take time to heal, during which time they are prone to fungal infections, especially on moist scars, which provide more receptive surfaces for fungi. Prolonged moisture in scars is more likely to occur when scars are in contact with the ground or when they are shaped such that they trap water.

In the next section we present several common scenarios in oak forest and woodland management where managers may want to use fire. We also discuss the consequences of burning stands at various times in the life cycle of an oak forest in terms of fire damage to trees and the stand.

SCENARIO 1: MATURE FOREST WITH NO OAK ADVANCE REPRODUCTION

Prescribed fire can be used to prepare the seedbed for a good acorn crop or in advance of artificial regeneration of oak by direct seeding or planting (Dey and others 2008a, 2012). Fire can reduce: (1) the physical barrier to oak seedling establishment created by deep litter, (2) seed of competitors stored in the forest floor, and (3) woody competitor density and structure in the mid- and understory. Litter in Central Hardwood forests accumulates rapidly after burning and in 4 years can return to 75 percent of pre-burn amounts (Stambaugh and others 2006). Midstory release is effective for a number of years but hardwood sprouts from top-killed stems will again begin competing with oak reproduction, although their rate of recovery is reduced by higher levels of overstory stocking (Dey and Hartman 2005, Lockhart and others 2000, Miller and others 2004). Therefore, fires may need to be repeated to manage litter depth for adequate oak seedling establishment and to sustain control over competing vegetation to favor oak seedling establishment and the development of large oak advance reproduction. Because bumper acorn crops occur only periodically and oaks grow slowly under low to moderate understory light levels, it may take 10 to 30 years to develop adequate numbers of large oak advance reproduction using combinations of stand thinning or shelterwood harvesting and prescribed burning. Scarring of merchantable stems or trees that will become merchantable by the time of harvest may lead to substantial loss of volume and value due to decay over 20 to 30 years (Loomis 1989, Stambaugh and Guyette 2008). An alternative method of midstory removal is to use an herbicide application to individual stems, the benefits of which include the avoidance of stem wounding by fire, the prevention of hardwood sprouts from undesirable species, and fewer treatments required for sustained control of competing species. Alternatively, the midstory may be mechanically removed, which avoids fire scarring of residual trees, but it does not prevent sprouting from cut stems.

SCENARIO 2: MATURE FORESTS WITH ABUNDANT SMALL OAK ADVANCE REPRODUCTION

This is a common situation in eastern oak forests, especially following a bumper acorn crop. Small oak advance reproduction (< 1 foot tall and 0.25 inches in basal diameter) have low regeneration potential, and midstory removal or shelterwood harvesting is often recommended to reduce stand density and deliver more light to the forest floor to promote oak seedling growth. Prescribed fire can be a useful tool for controlling competing woody stems that are < 4 inches d.b.h., but it has the potential to cause high mortality in small oak seedlings. Therefore, Brose (2008) and Brose and others (2013) recommend encouraging oak seedling growth with a shelterwood harvest that removes about 50 percent of the initial stand basal area, to about B-level stocking, and burning either just before or several years after final overstory removal. Once oak seedlings have become large (e.g., ≥ 0.75 inches basal diameter), then moderate- to high-intensity fires can increase the relative abundance of competitive oak reproduction (Brose 2011). Waiting as long as possible to conduct the release burn to allow the oak seedlings to grow increases their capacity to sprout vigorously following top-kill from the fire. Basal diameter in oak is an indicator of the size of the root system, which drives sprout growth (Dey and Parker 1997, Knapp and others 2006). For several years after each shelterwood harvest, oak seedlings will benefit from increased light levels. Monitoring the reproduction helps determine the need for and timing of prescribed burning. If the shelterwood is completely removed in 3 to 5 years after the initial cut, then fire scarring is not an issue. Scarring of residual trees that are retained for the long-term for wildlife or aesthetic purposes may reduce their longevity due to advanced decay in the lower bole, which renders trees more susceptible to breakage or blowdown in storms.

SCENARIO 3: STAND INITIATION STAGE AFTER FINAL SHELTERWOOD REMOVAL OR CLEARCUTTING

During the stand initiation stage (Oliver and Larson 1996) following clearcutting or final removal of the shelterwood, prescribed burning is effective in promoting oak dominance over competing woody vegetation, provided the oak advance reproduction is present in sufficient density before harvesting. Periodic fires (e.g., every 3 to 5 years) are useful for increasing the relative abundance of competitive oak seedlings (Brose and others 2013). Moderate to intense fires during early leaf out discriminate more in favor of oak if the oak reproduction is large (Brose 2011). As long as the majority of stems are < 4 inches d.b.h., burning, within typical prescriptions, will cause top-kill throughout the stand of reproduction, which with time will favor oak dominance. There are no long-term deleterious effects of burning at this stage of stand development unless there are larger overstory trees retained for wildlife habitat, aesthetics or other long-term purposes. Scarring of these stems may reduce their life span. At some point, burning must stop for a sufficiently long period to allow seedling sprouts to recruit into the overstory. This may take 10 to 30 years depending on growth rates and source of reproduction. Reproduction from stump sprouts grow initially more rapidly than seedling origin reproduction, reaching 2.3 to 3.1 inches d.b.h. in 10-year-old clearcuts in the Missouri Ozarks (Dey and others 2008b). White oak saplings that are codominant in Missouri clearcuts grow 1.5 inches in diameter per 10 years on sites of average site quality; at this rate it would take 20 years for a small diameter (1 inch d.b.h.) sapling to reach 4 inches d.b.h. and begin to improve its chances of surviving being top-killed by a low-intensity fire (Shifley and Smith 1982). A sufficient fire-free period is crucial to permit recruitment into the overstory.

SCENARIO 4: STEM EXCLUSION STAGE, CROWN CLOSURE

When regenerating stands reach the stem exclusion stage (Oliver and Larson 1996), continued use of prescribed burning indiscriminately causes top-kill and retards stand development. Setting back a stand at this point results in the loss of 20 years of growth. If oak trees still require release to maintain adequate stocking of dominant stems at this stage, it is better to use mechanical or chemical release methods applied as a crop tree or area-based thinning. The risk of fire scars in larger saplings at this stage can result in substantial degrade and volume loss at the time of harvest, especially if the wounds are large enough to remain open to fungal infections for several years.

SCENARIO 5: STANDS MANAGED BY UNEVEN-AGED METHODS

The use of uneven-aged methods, primarily single-tree selection, is not recommended for sustaining oak forests on mesic and hydric sites; however, there is evidence in the xeric forests of the Missouri Ozarks that it may be possible to sustain white oak forests by this method (Johnson and others 2009, Loewenstein 2005). Application of prescribed burning with single-tree selection management is highly likely to cause large amounts of defect in trees by the time they reach sawtimber size. In this silvicultural system, trees are harvested to simultaneously promote regeneration and recruitment into the overstory. Trees of all sizes exist in the stand, and sapling, poles and small sawtimber that sustain fire scars are likely to remain in the stand for decades before being harvested, thus, permitting time for advanced decay to develop. Also, the growth of trees in the mid- and understory is reduced by overstory stocking, and this increases the time it takes for fire scars to heal. Burning in uneven-aged stands also can disrupt the distribution of age classes because seedlings and saplings are susceptible to being top-killed or dying. With repeated burning, the regenerating cohort will be concentrated into a single (or few) age classes. The use of group selection has been advocated for oak regeneration because it provides more light to the regeneration than the single-tree method. However, controlling competing vegetation before and after harvesting is problematic in small random openings located throughout the forest. Without large oak advance reproduction at time of harvest, and control of competing vegetation, typically group openings are dominated by non-oak species (Jenkins and Parker 1998, Weigel and Parker 1997). The use of fire to control competing vegetation in isolated group openings is operationally impractical due to the small size of openings, lack of natural fire breaks around openings, and matrix of uncut or single-tree selection forest that is vulnerable to fire injury and decay.

SCENARIO 6: SAVANNA AND WOODLAND RESTORATION

Savannas and woodlands were once much more abundant across the landscape in the eastern United States, especially in the border region of the tallgrass prairie and eastern deciduous forests. An increasingly common management goal is to restore these ecosystems where forests now prevail. A primary objective is to reduce stand density using prescribed fire to promote development of native grass and forb ground flora typical of these communities (e.g., Nelson 2010). A challenge in restoration is how to reduce the density of larger overstory trees that have developed over the past 50 years or more since the commencement of fire suppression programs. Moderate- to high-intensity fires are needed to reduce overstory density in the larger size classes, which incidentally have the potential to scar the residual overstory trees and reduce their longevity in the overstory. Fire is also less specific about which trees are removed and which remain. An alternative to using fire to reduce stand density is to conduct a timber harvest. This permits recovery of wood products, avoids the problem of fire scarring residual trees, and provides better control over the distribution and composition of the final overstory. Lower intensity fires can be combined with timber harvesting and mechanical/chemical thinning to achieve other ecological objectives and control small hardwood sprouts. When it is time to replace the overstory in woodlands and savannas, a fire-free period is necessary for recruitment. Often there is present large oak advance reproduction because partial overstory density and periodic fire promote oak reproduction.

CONCLUSION

Small diameter trees that survive being burned can only have small wounds because if they had large wounds they would be completely girdled and suffer top-kill or mortality. If they are in a dominant competitive position and are vigorous, they can heal quickly, preventing fungal infection and rapidly compartmentalizing the injured tissue. Large diameter trees are harder to scar by fire due to their thicker bark. Because these larger trees are merchantable, the time to harvest may be nearing, and this limits wood decaying fungi from causing much volume or value loss. Fire scars on the lower end of the butt log are often outside the scaling cylinder and therefore do not affect product recovery or value. It is pole and small sawtimber-sized trees that are at greatest risk of sustaining large scars and remaining in the stand long enough to develop substantial decay. In oak forests and woodlands, prescribed fire is most useful to prepare for and manage regeneration of desirable species. It can be used without causing considerable loss in stand volume or value when incorporated as part of an evenaged silvicultural system. Intermediate-aged stands are at high risk to fire injury and damage; alternatives to fire are preferred for managing stand composition, growth, and quality in these stands. In any case, individual large-diameter trees are at risk of fire damage if the intention is to retain them for the long-term and they are subjected to high-intensity fires.

The use of prescribed fire in restoring and sustaining oak ecosystems does not have to have the same outcome as the history of wildfire, with its resultant forest damage and high amounts of standing live cull volume. Fire was an integral driver of the widespread distribution and dominance of oak, especially on mesic, high-quality sites. There are alternative management practices that can achieve similar outcomes, but sometimes fire is the most effective tool for achieving ecological objectives. Moreover, the silvics of oak species suggest several morphological characteristics that are well adapted to fire. Nonetheless, prescribed fire still has the potential to do damage to the forest and the trees if misapplied or used at the wrong stage of stand development. The extent of damage that develops in forests after fire depends on the silvicultural system and management goals. It is important to time fire use and control its severity by managing fire intensity and applying it judiciously when it is appropriate given stand structure, composition, and desired developmental trajectory. It is imperative to know what the positive and negative consequences are when using fire to sustain oak ecosystems. Fire can provide many ecological benefits; it can also cause much damage and value loss. Wise decisions on fire use derive from knowledge of fire effects on the array of biological, ecological, economic, environmental and social values, goods and services that come from oak ecosystems.

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