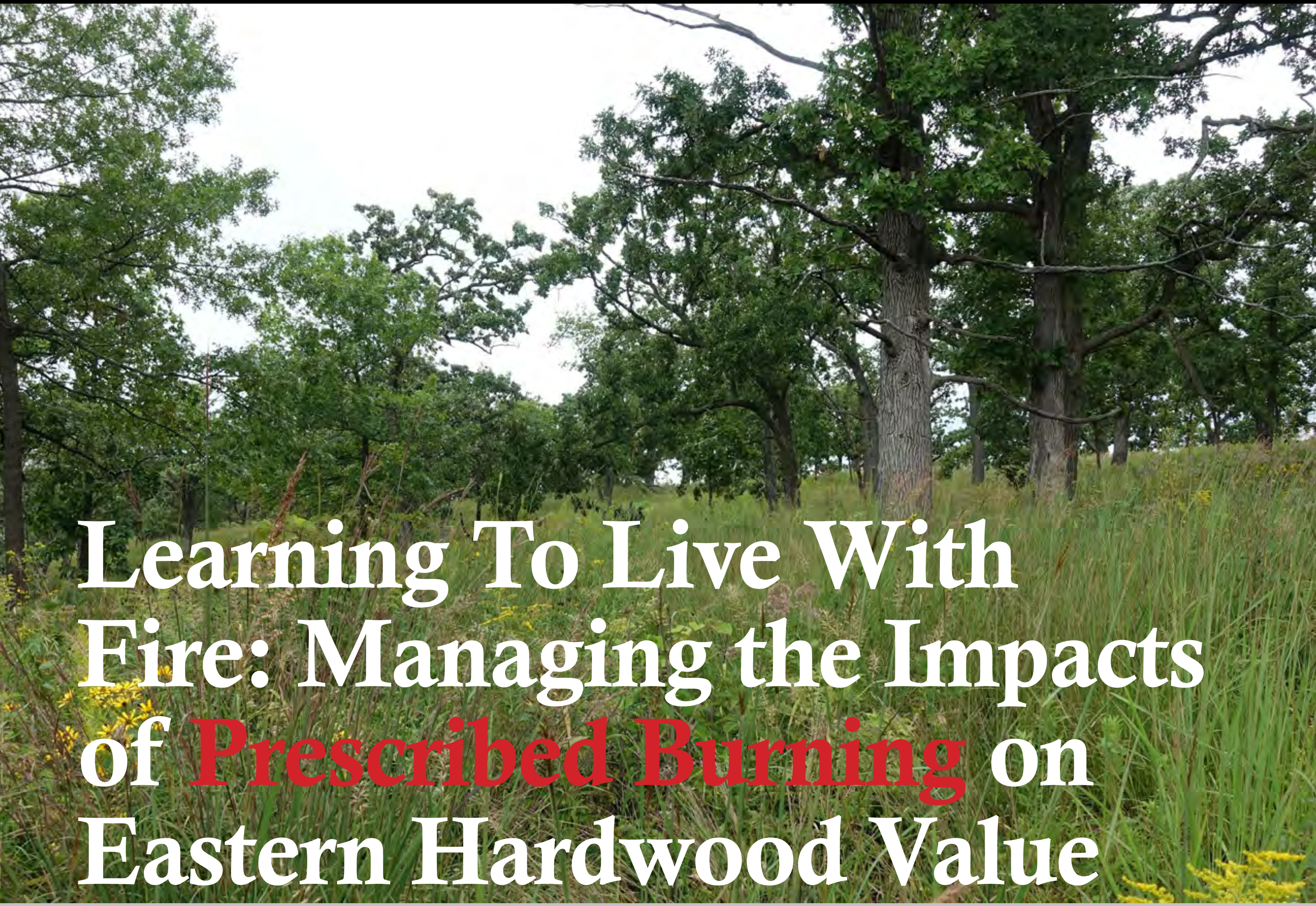

Learning To Live With Fire: Managing the Impacts of Prescribed Burning on Eastern Hardwood Value

Daniel C. Dey, Michael C. Stambaugh, and Callie J. Schweitzer

Oak savanna in southern Wisconsin. Photo: Dan Dey, USDA Forest Service, Northern Research Station.

Oak (*Quercus*) is a fire-adapted genus that has assumed dominance in forests, woodlands, and savannas over thousands of years during periods of frequent fire in North America (fig. 1). Fire has played an important and sustaining role in regeneration, competitive dynamics, rise to overstory dominance, and ecosystem structure and function in oak-dominated ecosystems.

Oak and pine *(Pinus)* were highly sought-after timber species during the initial logging boom of the late 19th and early 20th centuries, prized for their high quality and the diversity of forest products made from them during a period of frequent and mixed-severity fire regimes. It is somewhat ironic then, but understandable, that fire would come to be viewed as a negative, destructive force in American forestry, in part due to the catastrophic fires that burned over millions of acres and took thousands of lives.

Fires such as the Miramichi in Maine (1825), Peshtigo in Wisconsin (1871), and Hinckley in Minnesota (1894), along with the Big Blowup in the Northern Rockies (1910), all contributed to the national sentiment that fire must be controlled and eliminated from our forests and grasslands. The four Chiefs of the Forest Service who served after Gifford Pinchot from 1910 to 1939 all saw fireline action on the complex of fires that raged during the Big Blowup. They saw firsthand the devastation of timber and land wrought by wildfire. Consequently, early Forest Service policies and goals were to defeat fire and remove it from the landscape. By 1935, the formal policy was to suppress all fires by 10 a.m. on the day following their initial report.

An indirect influence on U.S. fire policy was the schooling that Gifford Pinchot and many other early leaders in American forestry received. Their formal training in forestry was in Germany and France, where intensive forest management for timber growth and yield left little room for fire in forestry. The ecological role of fire and the benefits of frequent light burning

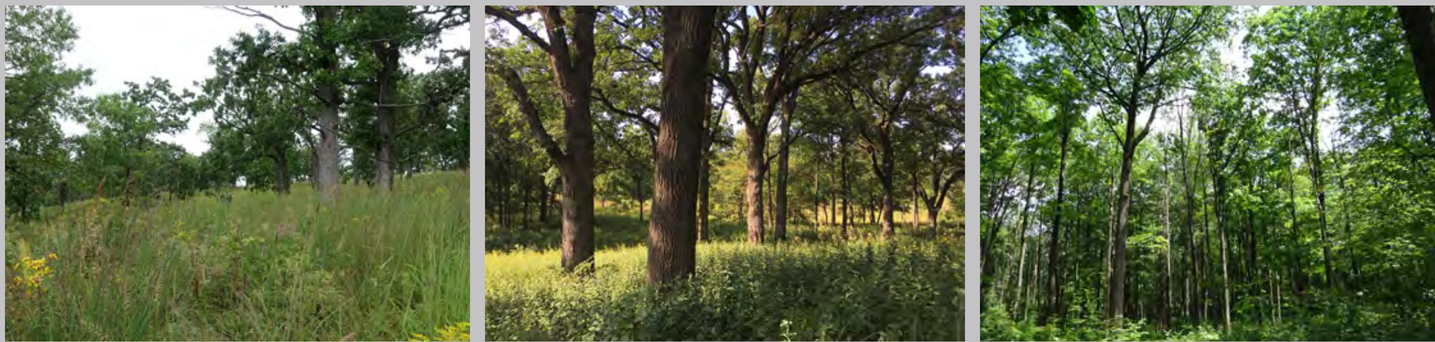

Figure 1—*Oak savannas (left, southern Wisconsin), woodlands (center, northern Illinois), and forests (Pennsylvania, right) were dominant oak ecosystems throughout the Eastern United States. Landscapes were diverse mosaics of these vegetation types, depending largely on the fire regime, topography, and human land use. Photos: Dan Dey, USDA Forest Service, Northern Research Station.*

were debated in the early 20th century, but the case for waging all-out war on wildland fire won out.

During the initial timber boom in the Eastern United States, entire regions were logged over within a short period of time in an era of exploitation from the mid-19th to early 20th centuries. Frequent to annual wildfires were ignited by settlers to promote browse and forage for open-woods grazing, to convert forests to agriculture, and for other reasons. These fires burned through logging slash, often under high-fire-danger weather conditions, severely scarring surviving trees.

Over the decades, substantial amounts of decay developed in the lower boles of the wounded trees, causing high amounts of volume, quality, and value loss due to decay and lumber grade defects. Estimates that half of the standing live timber was cull were common throughout the eastern hardwood region (Burns 1955; Gustafson 1944; Hepting 1937; Kaufert 1933). It is then understandable why foresters were taught about the destructiveness of fire in forests. Fire was relegated to accomplishing singular and very specific tasks, such as consuming logging slash and preparing sites for planting or natural regeneration. Under more sustainable forest management and fire suppression practices since the mid-20th century, merchantable volume, quality, and value increased in eastern hardwood forests by the early 21st century (Oswalt and others 2019).

Barriers to expanding the use of prescribed fire limit the treatment of a vast portion of the Nation's forests.

Prescribed fires in eastern hardwood forests generally result in a low level of overstory mortality (less than 5 percent loss of basal area).

For the better part of the 20th century, fire was an enemy to be defeated, and our ability to do so increased as national and State forestry agencies were established with a primary mission of fire suppression. Our ability to suppress fires was greatly advanced by the men returning home from World War II and the ready availability of military heavy equipment and aircraft. At about the same time (in 1944), Smokey Bear began delivering his message against human-caused forest fires, a successful advertising campaign that helped to shape public opinion regarding wildland fire.

RETHINKING OUR RELATIONSHIP WITH FIRE

In the past 30 years, we have witnessed the increase in frequency, size, and severity of megafires (wildfires 100,000 acres (40,000 ha) or more in size), especially in the Western United States. Many of the underlying factors arise from decades of widespread fire suppression, which set the stage for megafires in an era of increasing drought frequency and severity, higher seasonal and annual temperatures, and prolonged fire seasons. Initial regional exploitative logging, followed by declining levels of active management, have resulted in homogeneous landscapes that are vulnerable to widespread mortality from insects and diseases as well as megafires.

Decades of fire exclusion across the country have resulted in landscapes characterized by unprecedentedly high levels of forest density and fuel loading and complex vertical tree canopy and fuel structure. These changes in fuel conditions have resulted in forests with low resistance and resilience to disturbances; fires of higher intensity, size, and severity; and increased chances of crown fires. In the aftermath of megafires, catastrophic floods and debris flows degrade waterways, riparian resources, and lowland communities. Megafires inhibit forest regeneration over large areas for prolonged periods or even cause vegetation type conversions from forests to grasslands or shrublands.

More recently, we have been seeing the ecological impacts of fire exclusion in the loss of native biodiversity, landscape diversity, prairies, savannas, and woodlands. We are also seeing the disruption of ecosystem processes such as regeneration. Such disruptions inhibit sustainability and promote the transition toward novel forest composition and structure, which in many ways are less desirable for human well-being.

In the 1990s, the idea of an appropriate management response to fire suppression began to replace the 10 A.M. Policy, and it was formally adopted in 2008. In 2014, the National Cohesive Wildland Fire Management Strategy was finalized, presenting a new vision for national fire policy (WFLC 2014): "To safely and effectively extinguish fire, when needed; use fire where allowable; manage our natural resources; and, as a Nation, live with wildland fire." From 1947 to 2001, Smokey Bear went from saying "Only you can prevent forest fires" to "Only you can prevent wildfires." Room has been made in forest and wildland fire management for prescribed fire and managed wildfires.

The need to restore fire in fire-dependent forests and grasslands is great over substantial portions of the United States.

PRESCRIBED FIRE IN THE UNITED STATES

By the end of the 20th century, the negative ecological consequences of all-out fire suppression were beginning to be recognized in terms of:

- The loss of key wildlife habitat, landscape diversity, and native biodiversity;
- Increasing forest regeneration problems in fire-dependent systems;
- Increasing fuel loading and hazardous fuel conditions as forests became denser and structurally complex,
- Woody encroachment in grassland and shrubland ecosystems; and
- Widespread forest health outbreaks, resulting in catastrophic tree mortality over millions of acres.

The need to restore fire in fire-dependent forests and grasslands was great over substantial portions of the United States. In addition, using prescribed fire or managed wildfire to reduce the occurrence of high-severity wildfires that threaten communities was an increasingly important strategy in managing landscapes and regions.

From 1998 to 2015, approximately 2.2 million acres (0.9 million ha) per year were prescribe-burned on average by Federal, State, and other forest (including range) landowners (Melvin 2018; NIFC 2020). Since 2016, the area of forests and rangelands burned under prescription has increased, rising to 8.8 million acres (3.5 million ha) in 2018 (Melvin 2018). Most (70–80 percent) of the prescribed fires occur in the Southeastern United States, and most of those are to manage southern pine forests, plantations, and woodlands (Kolden 2019; Melvin 2018; Schweitzer and Dey 2020, in this issue).

This level of prescribed burning is only half or less of what it should be to manage fuels and reduce the risk of high-severity fires on national forest lands and other lands across the Nation (Kolden 2019; North and others 2012, Vaillant and Reinhardt 2017). The need for prescribed fire is even greater when one considers the potential for it to restore ecosystem processes important to increasing the regeneration potential of desired tree species such as oaks and pines; providing for landscape diversity and resilience; and restoring long-lost native woodland, savanna, and grassland habitats important to native wildlife, plant species, and other biodiversity of conservation concern.

Leenhouts (1998) estimated that 86 to 212 million acres (34–85 million ha) burned per year in the conterminous United States before the industrial period (about 200 to 500 years ago) but that only 12 to 17 million acres (5–7 million ha) burn per year now. He estimated that 44 to 106 million acres (18–42 million ha) of fire-deficient forests and grasslands are in need of burning each year to restore ecosystem form and function.

RELUCTANCE TO USE PRESCRIBED FIRE

Many historically fire-dependent, frequent-fire ecosystems in the United States are now more dense with vegetation and have higher fuel loading than ever before. Combinations of forest thinning and repeated prescribed fire have been shown to be effective in ameliorating future wildfire behavior and severity; restoring historic open forest structure and fire regimes; increasing native floral diversity; improving habitat conditions for many wildlife species; returning critical ecosystem processes and function; and avoiding the environmental degradation that follows catastrophic, high-severity megafires (Fontaine and Kennedy 2012; Fulé and others 2012; Kalies and Yocom Kent 2016; McIver and others 2013; Schwilk and others 2009; Stephens and others 2012).

However, barriers to expanding the use of prescribed fire limit the treatment of a vast portion of the Nation's forests, even though they are fire deficient and hence of low resilience to future perturbations, contributing to catastrophic forest mortality and wildfires. Calkin and others (2015), Melvin (2018), and Schultz and others (2019) have identified barriers to the increased use of managed wildfires and prescribed fires, such as:

- Agency capacity to manage fires,
- Unfavorable weather,
- Smoke-related air quality concerns,
- Agency policies and rewards that act as disincentives to managers and negatively alter their perception of personal risk to do anything other than suppress fires, and
- A disconnect between fire and forest management.

A specific additional barrier to the use of prescribed fire in eastern hardwood forests is manager and landowner concern about negative fire effects on timber volume, quality, and value.

In the hardwood forest products industry, the quality of trees, logs, and lumber is paramount in importance in determining their value. For example, the 2018 (fourth-quarter) price differential for Kentucky white oak *(Quercus alba)* sawlogs by quality class per thousand board feet (MBF) was (University of Kentucky, n.d.):

Figure 2—*Prescribed fires are often conducted in the dormant season (September to April) in eastern hardwood ecosystems. They are typically low to moderate in intensity and severity. Backing and flanking fires (top) are commonly set to establish safe control lines. Then strip head fires or gridded spot fires (center and bottom) are lit to burn out the core of the unit. A wide array of ignition strategies and methods can be used to keep fires in prescription and meet management objectives. Controlling fire temperature and duration are key to minimizing damage to valuable timber and overstory trees. Photos: Dan Dey, USDA Forest Service, Northern Research Station.*

- High quality..........................$1,238
- Medium quality $743
- Low quality $320

High-quality white oak stave logs used in the spirits barrel industry were valued at $1,363 per MBF.

Lumber prices in Indiana for 2018 reflect the value difference by quality (Settle and Gonso 2018). FAS (Firsts and Seconds) and Premium white oak lumber brought $1,675 per MBF, compared to $1,030 and $570 per MBF for no. 1C and no. 2A lumber, respectively.

Fire injuries to tree boles can lead to volume loss through wood decay and quality grade reductions caused by mineral stain, shakes, and checks, which have a very real impact on agency and landowner financial returns. No wonder that foresters and landowners are hesitant to set fire to their woods.

PRESCRIBED FIRE DAMAGE TO TREES: OVERSTORY MORTALITY

Prescribed fire is normally conducted in a way and under conditions that result in low to moderate fire behavior and severity (fig. 2). Although it is possible to kill large overstory trees with prescribed fire, using fire to manage the overstory is not normally an objective of the burn. Reductions in overstory density are often better achieved through commercial thinning or timber harvesting, which are more efficient and effective than fire in managing overstory density and spatial arrangement. In addition, revenues from commercial sales can be used to offset the other costs of restoration and management.

Fire is good for managing seedlings and saplings, shrubs, herbaceous plants, and surface fuels. Prescribed fires in eastern hardwood forests generally result in a low level of overstory mortality (less than 5 percent loss of basal area) (fig. 1) (Hutchinson and others 2005; Kinkead and others 2017; Regelbrugge and Smith 1994; Smith and Sutherland 2006). Oaks have a number of fire adaptations that aid in their persistence and dominance in frequent fire regimes (fig. 3), including:

- High ability to resprout as seedlings and saplings after fire kills the shoot;
- Rapid diameter growth and wound closure as sprouts arise from well-developed root systems;
- Ability to compartmentalize fire injury, especially in white oak species; and
- Development of thick bark in maturing trees.

PRESCRIBED FIRE DAMAGE TO TREES: RESISTANCE TO STEM INJURY

Prescribed fire is quite capable of wounding trees, even large overstory trees (fig. 3). Tree injury usually occurs at the base of the tree when fire kills cambial tissue. This may lead to an open wound that permits fungal and bacterial infections to enter the tree bole. With time, wood decay may advance, causing volume loss. The injury and infection also commonly cause mineral stain, checks, shakes, and other grade defects in the tree that reduce its forest product value.

Basal wounds that affect the lowest part (butt log) of the tree are significant because most of the tree's volume is in the butt log; the potential for having the highest grade and value forest products, such as stave and veneer logs, is therefore in the butt log. There is much at risk when a tree is injured at the base by fire or mechanical means. A more thorough review of prescribed fire effects on tree mortality, injury, and economic loss is presented by Dey and Schweitzer (2018) and Wiedenbeck and Smith (2019).

The amount of tree wounding by fire depends on several factors:

- Fire temperature and duration of heating;
- Tree characteristics such as species, tree diameter, bark thickness, and physiological activity; and
- Ambient environmental conditions, including air temperature.

Of course, higher fire temperatures of longer duration are increasingly capable of killing cambium tissue. Trees vary in their ability to resist cambial injury, based primarily on bark thickness. Bark is a good insulator of the cambium from the heat of fire, and bark thickness increases with increasing tree diameter. As bark increases in thickness, there is an exponential degree of protection of the cambium from high fire temperatures (Hare 1965; Pausas 2015; Vines 1968). Bark accumulates at different rates, with increasing diameter growth, depending on the species.

Figure 3—*Post, chinkapin, black, and white oaks resprout (top left) in a frequently burned oak/pine woodland in the Missouri Ozarks. Oaks are known for their ability to resprout after a shoot is lost to fire. White oak species are especially able to compartmentalize injuries to the bole (top right) and contain the spread of fungi and bacteria that otherwise would cause wood decay and mineral stain, lowering the volume and value of the wood. This white oak was injured by fire when young and small in diameter but was able to contain the damage in the core of the bole and produce clear wood afterwards; red oak species are more susceptible to decay. Thick bark develops on a bur oak (bottom left) as it grows in diameter; typical of many oak species, the thickness of the bark helps to protect the cambium from fire injury, but scarlet and pin oaks have thinner bark and less resistance to fire injury. Trees capable of rapid diameter growth (bottom right) following fire injury are able to quickly cover over open wounds and minimize fungal infections that lead to rot. However, the bark on the woundwood is thinner and susceptible to injury in future fires. Photos: Tree cross section photo by Michael Stambaugh, University of Missouri, The School of Natural Resources; all others by Dan Dey, USDA Forest Service, Northern Research Station.*

In general, upland species have thicker bark than bottomland species for similar-sized trees in eastern North America (Sutherland and Smith 2000). Bark thickness is greatest in white oak group species (*Quercus* section *Quercus*) followed by the red oak group species (*Quercus* section *Lobatae*). Resistance to scarring decreases in upland oaks, from post oak (*Q. stellata* Wangenh.) and bur oak (*Q. macrocarpa* Michx.), to white oak (*Q. alba* L.), to black oak (*Q. velutina* Lam.), to southern red oak (*Q. falcata* Michx.), to scarlet oak (*Q. coccinea* Muenchh.) (Hengst and Dawson 1994; Kinkead and others 2017; Scowcroft 1966; Stevenson and others 2008). Species with inherently thinner bark include American beech (*Fagus grandifolia* Ehrh.), flowering dogwood (*Cornus florida* L.), black cherry (Prunus serotina Ehrh.), maples (*Acer* spp.), and hickories (*Carya* spp.).

The rate of bark thickening during growth is important because faster growth rates allow trees to earlier reach critical thresholds of thickness 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 (Hengst and Dawson 1994; Wiedenbeck and Schuler 2014). 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. montana* L.) and bur oak. The bark of southern yellow pines confers a high degree of resistance to fire scarring (Kinkead and others 2017; Stevenson and others 2008). Once a tree is scarred by a fire, it is more vulnerable to additional scarring in future fires because the bark is thin on the callus wood forming over the original scar.

PRESCRIBED FIRE DAMAGE TO TREES: RESPONSE TO STEM INJURY AND DECAY

Trees have several defense mechanisms to inhibit decay, including rapid diameter growth, compartmentalization, and heartwood resistance. Open wounds are susceptible to fungal and bacterial infection that leads to internal decay, and the faster a tree is able to close over wounds, the lower the probability that decay will occur (fig. 4). Diameter growth rates vary by species, site productivity, tree vigor and health, and stand density/competition. Larger wounds prolong the time a wound is exposed to infection.

Trees have several defense mechanisms to inhibit decay, including rapid diameter growth, compartmentalization, and heartwood resistance.

Figure 4—*Small oaks that are dominant on productive sites can grow rapidly enough in diameter to close small fire injuries in a few years (top left). More severely damaged small trees that have slower growth potential or are repeatedly wounded by fire can develop large catfaces that serve as entry points for wood-decaying fungi (top right). Because such trees may persist in forests for decades, substantial decay can develop. Concentrations of large fuels against the boles of trees, even mature thick-barked oaks, can cause severe fire injuries (bottom left). These wounds develop into large catfaces (bottom right), increasing the likelihood of repeated fire injuries and serving as entry points for fungi that cause advanced decay in the butt log. Photos: Dan Dey, USDA Forest Service, Northern Research Station.*

For example, Stambaugh and others (2017) observed that fire scars in mature white oak averaged 3.5 inches (8.9 cm) in width and took, on average, 10 years to close in a Missouri oak woodland managed by prescribed burning; but larger scars (9 inches (23 cm) wide) took up to 24 years to close. Mature trees in the Central Hardwood Region that were scarred in logging operations took 10 to 13 years for 59 percent to 76 percent, respectively, of the trees to close wounds (Smith and others 1994; Jensen and Kabrick 2014). Decay progresses more rapidly in red oak species and sugar maple (*Acer saccharum* Marsh.) (Forest Products Laboratory 1967; Hesterberg 1957).

If fire is applied judiciously and in a manner to minimize scarring of the bole, then value loss can be managed.

Fire frequency has an effect on potential scar sizes, with percent of trees scarred and scar size lower in annual than in periodic fire regimes (that is, with fires every 4 to 5 years) (Knapp and others 2017; Scowcroft 1966, Stambaugh and others 2014). Periodic fires can retard wound closure by repeatedly wounding the thinner barked woundwood. Prescriptions to promote oak or pine regeneration or to restore oak/pine woodlands and savannas often combine overstory thinning and prescribed fire. Burning in such stands with slash increases not only the percentage of trees scarred but also the average scar size in oaks (Kinkead and others 2017).

Compartmentalization is a process by which a tree establishes a defensive barrier around an injury, thus limiting the spread of fungi and bacteria throughout the bole (fig. 5) (Smith 2015). The ability to compartmentalize wounds varies by species; for example, the birches (*Betula* spp.) are less effective at it 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). Resistance to the spread and development of decay in the heartwood varies by species. Species of the white oak group, black locust (*Robinia pseudoacacia* L.), catalpa (*Catalpa* spp.), black cherry, eastern redcedar (*Juniperus virginiana* L.), and cypress (*Taxodium* spp.) have heartwood that ranges from 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.

Figure 5—*This mature white oak was wounded by fire in a northern Missouri woodland but was able to compartmentalize the fire injury, close over the open wound, and thereby minimize wood loss to decay. Some mineral stain has formed in reaction to the injury and infection, which degrades lumber value. Since fire injuries occur on the large end of the butt log, any damage remains outside of the scaling cylinder for a time and hence has minimal impact on log and lumber value. Harvesting injured trees within 5 to 10 years after injury also minimizes volume and value loss. Photo: Dan Dey, USDA Forest Service, Northern Research Station.*

TREE AND STAND VOLUME, GRADE, AND VALUE LOSS

In individual tree assessments of fire damage and loss, Marschall and others (2014) reported an increase in both value and volume loss to decay and a decrease in lumber grade in Missouri Ozark black oak, northern red oak (*Q. rubra* L.), and scarlet oak butt logs with increasing prescribed fire severity and initial fire scar size as represented by scar height and scar depth (fig. 6). Most of the devaluation in the butt log resulted from declines in lumber grade and not from volume loss. However, they found that scaled volume loss averaged only 4 percent and value loss averaged 10 percent after 14 years from fire injury. They concluded that, where less than 20 percent of the bole circumference was scarred and scar heights were less than 20 inches (51 cm), the value loss would be insignificant within 15 years of scarring; they found that harvesting the most severely injured trees within 5 years limits value loss.

In other studies, Loomis (1974) also reported 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 less than 40 inches (102 cm) after low-intensity prescribed fires in Ohio. They observed that most wounds occurred near the ground and were covered by intact bark, were small in size, and were rapidly and effectively compartmentalized within 2 years of the fire. Wiedenbeck and Schuler (2014) reported fire-related decreases in lumber quality that ranged from 7 percent in yellow-poplar to 12–13 percent in red and white oak and 16 percent in red maple (*Acer rubrum* L.) 5 to 8 years after two prescribed fires in West Virginia oak/mixed hardwood stands.

At the stand level, anywhere from 30 to 67 percent of trees can be scarred by fire in upland oak forests that are subjected to repeated prescribed fires over several decades (Knapp and others 2017; Mann and others 2020; Stevenson and others 2008; Stanis and others 2019). Stanis and others (2019) reported minor losses in volume and tree grade for a mix of

Figure 6—*Decay and stain associated with a fire-scarred red oak in Missouri, defects in the wood that developed within 15 years of the fire injury. Photo: Dan Dey, USDA Forest Service, Northern Research Station.*

hardwood species that had experienced one to more than four prescribed fires over a 25-year period in southern Indiana. They found that relative volume of the butt log decreased by less than 2.5 percent where there were three fires or less and averaged 6 percent in trees that were burned four times or more. Only 3.3 percent of the trees showed a decrease in tree grade overall, but 7 percent of the trees burned four times or more had a decrease in grade. Grade change was least in white oak.

On four national forests in the Central Hardwood Region, Mann and others (2020) evaluated the loss in butt log volume and value at the stand level in forests that received one to four or more prescribed fires over a 25-year period. About one-third of the trees were scarred and 6.6 percent had a decline in tree grade. They found that the relative volume of the butt log decreased by 1 to 2 percent on the Hoosier, Wayne, and Daniel Boone National Forests and by 10 percent on the Mark Twain National Forest. Volume loss varied by species or species group, with red oaks (13 percent) and sugar maple (10 percent) losing the most compared to white oaks (2 percent). Loss was significantly greater in trees that experienced four or more burns. Relative value loss in the butt log ranged from 1 to 3 percent on the three more easterly national forests to 15 percent on the Mark Twain National Forest. White oaks and yellow-poplar had the least loss in value (4.5 percent) compared to sugar maple (10 percent) and red oaks (13 percent).

Losses from wildfires are substantially greater than from prescribed fires. For example, Reeves and Stringer (2011) estimated that timber value loss averaged 47 percent, including cull volume, mortality, and changes in species and size classes in Kentucky hardwood forests. In contrast, overstory mortality is low in most prescribed burns, and value loss is predominately limited to changes in tree, log, and lumber grade.

However, Knapp and others (2017) demonstrated the importance of fire-induced shifts in species composition from higher to lesser valued species over time. They concluded that the greater loss in stand value in a Missouri Ozark oak forest was due to changes in species composition from white oak to post oak after 60 years of prescribed fire. Thus, losses due to wood decay can be minimized if fire intensity and duration are low, fires are ignited in a way that limits scarring, scarred trees are harvested before decay advances into the log scaling cylinder, and forests are managed to prevent shifts in composition to lower valued species.

PROMISING RESULTS

An increasing number of goals and objectives, including reducing wildfire risk and severity as well as ecosystem restoration, require forest managers to incorporate prescribed fire into the management system and at the landscape level. There are many reasons why managers are reluctant to apply prescribed fire and manage wildfire on large acreages. However, the current level of prescribed burning is orders of magnitudes below what is needed or possible.

Recent research on the effects of fire on hardwoods has begun to shed light on a concern about timber loss from fire due to scarring and subsequent decay. Many forest managers fear a corresponding loss of grade as well as timber volume and value in the highly profitable fine hardwoods. Early results are very promising, showing less than 5 to 10 percent loss of volume or value, depending on the circumstances in the short term.

If fire is applied judiciously and in a manner to minimize scarring of the bole, then value loss can be managed through periodic harvesting of wounded trees before decay and loss of grade advance into the scaling cylinder. Much more research and application of prescribed fire is needed to fine-tune its use in eastern hardwood forests. By quantifying the loss in volume and value of fire-injured timber, managers can make better decisions about balancing the benefits of prescribed fire against the potential costs. The actual loss so far has been shown to be in line with other traditional costs of forest management. And the costs may be seen as entirely acceptable when the ecological gains are considered.

LITERATURE CITED

Burns, P.Y. 1955. Fire scars and decay in Missouri oaks. Columbia, MO: University of Missouri, College of Agriculture, Agriculture Experiment Station. 8 p.

Calkin, D.E.; Thompson, M.P.; Finney, M.A. 2015. Negative consequences of positive feedbacks in United States wildfire management. Forest Ecosystems. 2: 9. DOI: 10.1186/s40663-015-0033-8.

Dey, D.C.; Schweitzer, C.J. 2018. A review on the dynamics of prescribed fire, tree mortality, and injury in managing oak natural communities to minimize economic loss in North America. Forests. 9(8): 461. 22 p. DOI: 10.3390/f9080461.

Fontaine, J.B.; Kennedy, P.L. 2012. Meta-analysis of avian and small-mammal response to fire severity and fire surrogate treatments in U.S. fire-prone forests. Ecological Applications. 22(5): 1547–1561.

Forest Products Laboratory. 1967. Comparative decay resistance of heartwood of native species. Res. Note FPL–0153. Madison, WI: USDA Forest Service, Forest Products Laboratory. 2 p.

Fulé, P.Z.; Crouse, J.E.; Roccaforte, J.P.; Kalies, E.L. 2012. Do thinning and/or burning treatments in Western USA ponderosa or Jeffrey pine-dominated forests help restore natural fire behavior? Forest Ecology and Management. 269: 6–81.

Gustafson, R.O. 1944. Cull as determined from basal wounds in Kentucky highlands timber. Journal of Forestry. 42: 181–184.

Hare, R.C. 1965. The contribution of bark to fire resistance of southern trees. Journal of Forestry. 63: 248–251.

Hengst, G.E.; Dawson, J.O. 1994. Bark properties and fire resistance of selected tree species from the Central Hardwood Region of North America. Canadian Journal of Forest Research. 24: 688–696.

Hepting, G.H. 1937. Decay in merchantable oak, yellow poplar, and basswood in the Appalachian Region. Washington, DC: USDA Forest Service. 30 p.

Hesterberg, G.A. 1957. Deterioration of sugar maple following logging damage. St. Paul, MN: USDA Forest Service, Lake States Forest Experiment Station. 58 p.

Hutchinson, T.F.; Sutherland, E.K.; Yaussy, D.A. 2005. Effects of repeated prescribed fires on the structure, composition, and regeneration of mixed-oak forests in Ohio. Forest Ecology and Management. 218: 210–228.

Jensen, R.G.; Kabrick, J.M. 2014. Following the fate of harvest damaged trees 13 years after harvests. In: Groninger, J.W.; Holzmueller, E.J.; Nielsen, C.K.; Dey, D.C., eds. Proceedings, 19th Central Hardwood Forest Conference. Gen. Tech. Rep. NRS–P–142. Newtown Square, PA: USDA Forest Service, Northern Research Station: 199–200.

Kalies, E.L.; Yocom Kent, L.L. 2016. Tamm review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review. Forest Ecology and Management. 375: 84–95.

Kaufert, F.H. 1933. Fire and decay injury in the southern bottomland hardwoods. Journal of Forestry. 31: 64–67.

Kinkead, C.S.; Stambaugh, M.C.; Kabrick, J.M. 2017. Mortality, scarring, and growth in an oak woodland following prescribed fire and commercial thinning in the Ozark Highlands. Forest Ecology and Management. 403: 12–26.

Knapp, B.O.; Marschall, J.M.; Stambaugh, M.C. 2017. Effects of long-term prescribed burning on timber value in hardwood forests of the Missouri Ozarks. In: Kabrick, J.M.; Dey, D.C.; Knapp, B.O. [and others], eds. Proceedings of the 20th Central Hardwood Forest Conference. Gen. Tech. Rep. NRS–P–167. Newtown Square, PA: USDA Forest Service, Northern Research Station: 304–313.

Kolden, C.A. 2019. We're not doing enough prescribed fire in the Western United States to mitigate wildfire risk. Fire. 2(2): 30. DOI: 10.3390/fire2020030.

Leenhouts, B. 1998. Assessment of biomass burning in the conterminous United States. Conservation Ecology. 2(1): 1. Available from the Internet. URL: *http://www.consecol.org/vol2/iss1/art1/.* (6 February 2020).

Loomis, R.M. 1974. Predicting the losses in sawtimber volume and quality from fires in oak-hickory forests. Res. Pap. NC–104. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station. 6 p.

Mann, D.P.; Wiedenbeck, J.K.; Dey, D.C.; Saunders, M.R. 2020. Evaluating economic impacts of prescribed fire in the Central Hardwood Region. Journal of Forestry. DOI: 10.1093/jofore/fvaa004.

Marschall, J.M.; Guyette, R.P.; Stambaugh, M.C.; Stevenson, A.P. 2014. Fire damage effects on red oak timber product value. Forest Ecology and Management. 320: 182–189.

McIver, J.D.; Stephens, S.L.; Agee, J.K. [and others]. 2013. Ecological effects of alternative fuel-reduction treatments: highlights of the National Fire and Fire Surrogate study (FFS). International Journal of Wildland Fire. 22: 63–82.

Melvin, M. 2018. 2018 national prescribed fire use survey report. Tech. Rep. 03–18. Coalition of Prescribed Fire Councils, Inc. 23 p. *https://www.stateforesters.org/wp-content/uploads/2018/12/2018-Prescribed-Fire-Use-Survey-Report-1.pdf.* (6 February 2020).

NIFC (National Interagency Fire Center). 2020. Prescribed fires and acres by agency, 1998–2018. *https://www.nifc.gov/fireInfo/fireInfo_stats_prescribed.html.* (25 January 2020).

North, M.; Collins, B.M.; Stephens, S.L. 2012. Using fire to increase the scale, benefits, and future maintenance of fuels treatments. Journal of Forestry. 110(7): 392-401.

Oswalt, S.N.; Smith, W.; Miles, P.D.; Pugh, S.A., coords. 2019. Forest Resources of the United States, 2017: a technical document supporting the Forest Service 2020 RPA Assessment. Gen. Tech. Rep. WO-97. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 223 p. https://doi.org/10.2737/WO-GTR-97

Pausas, J.G. 2015. Bark thickness and fire regime. Functional Ecology. 29: 315–327.

Reeves, C.; Stringer, J. 2011. Wildland fires' long-term costs to Kentucky's woodlands. Kentucky Woodlands Magazine. 6(3): 6–7.

Regelbrugge, J.C.; Smith, D.W. 1994. Postfire tree mortality in relation to wildfire severity in mixed oak forests in the Blue Ridge of Virginia. Northern Journal of Applied Forestry. 11: 90–97.

Schultz, C.A.; Thompson, M.A.; McCaffrey, S.M. 2019. Forest Service fire management and the elusiveness of change. Fire Ecology. 15:13 doi:10.1186/s42408-019-0028-x

Schweitzer, C.; Dey, D. 2020. Coproducing science on prescribed fire, thinning, and vegetation dynamics on a national forest in Alabama. Fire Management Today. 78(3): 42–50.

Schwilk, D.W.; Keeley, J.E.; Knapp, E.E. [and others]. 2009. The national fire and fire surrogate study: effects of fuel reduction methods on forest vegetation structure and fuels. Ecological Applications. 19(2): 285–304.

Scowcroft, P.G. 1966. The effects of fire on the hardwood forests of the Missouri Ozarks. Columbia, MO: University of Missouri. Master's thesis. *https://www.researchgate.net/publication/36026587_The_effects_of_fire_on_the_hardwood_forests_of_the_Missouri_Ozarks_microform.* (29 July 2018).

Settle, J; Gonso, C. 2018. 2018 Indiana forest products price report and trend analysis. Indianapolis, IN: Indiana Division of Forestry, Department of Natural Resources. 27 p. *https://www.in.gov/dnr/forestry/files/fo-spring_2018_Timber_Price_Report.pdf.* (26 January 2020).

Smith, H.C.; Miller, G.W.; Schuler, T.M. 1994. Closure of logging wounds after 10 years. Res. Pap. NE–692. Radnor, PA: USDA Forest Service, Northeast Forest Experiment Station. 6 p.

Smith, K.T. 2015. Compartmentalization, resource allocation, and wood quality. Current Forestry Reports. 1(1): 8–15.

Smith, K.T.; Sutherland, E.K. 1999. Fire scar formation and compartmentalization in oak. Canadian Journal of Forest Research. 29: 166–171.

Smith, K.T.; Sutherland, E.K. 2006. Resistance of eastern hardwood stems to fire injury and damage. In: Dickinson, M.B., ed. Fire in eastern oak forests: delivering science to land managers. Newtown Square, PA: USDA Forest Service, Northern Research Station: 210–217.

Stambaugh, M.C.; Marschall, J.M.; Guyette, R.P. 2014. Linking fire history to successional change of xeric oak woodlands. Forest Ecology and Management. 320: 83–95.

Stambaugh, M.C.; Smith, K.T.; Dey, D.C. 2017. Fire scar growth and closure rates in white oak *(Quercus alba)* and the implications for prescribed burning. Forest Ecology and Management. 391: 396–403.

Stanis, S.; Wiedenbeck, J.; Saunders, M.R. 2019. Effect of prescribed fire on timber volume and grade in the Hoosier National Forest. Forest Science. 65(6): 714–724.

Stephens, S.L.; McIver, J.D.; Boerner, R.E.J. [and others]. 2012. The effects of forest fuel-reduction treatments in the United States. BioScience. 62(6): 549–560.

Stevenson, A.P.; Muzika, R-M; Guyette, R.P. 2008. Fire scars and tree vigor following prescribed fires in Missouri Ozark upland forests. In: Jacobs, D.F.; Michler, C.H., eds. Proceedings, 16th Central Hardwood Forest Conference. Gen. Tech. Rep. NRS–P–24. Newtown Square, PA: USDA Forest Service, Northern Research Station: 525–534.

Sutherland, E.K.; Smith, K.T. 2000. Resistance is not futile: the response of hardwoods to fire-caused wounding. In: ; Yaussy, D.A., ed. Workshop on fire, people, and the Central Hardwoods landscape. Newtown Square, PA: USDA Forest Service, Northeastern Research Station: 111–115.

University of Kentucky. [N.d.]. Delivered timber prices. Lexington, KY: College of Agriculture, Food and Environment, Department of Forestry and Natural Resources. *http://forestry.ca.uky.edu/delivered-timber-prices.* (26 January 2020).

Vaillant, N.M.; Reinhardt, E.D. 2017. An evaluation of the Forest Service hazardous fuels treatment program—are we treating enough to promote resiliency or reduce hazard? Journal of Forestry. 115(4): 300–308.

Vines, R.G. 1968. Heat transfer through bark, and the resistance of trees to fire. Australian Journal of Botany. 16: 499–514.

Wiedenbeck, J.K.; Schuler, T.M. 2014. Effects of prescribed fire on the wood quality and marketability of four hardwood species in the central Appalachian region. In: Groninger, J.W.; Holzmueller, E.J.; Nielsen, C.K.; Dey, D.C., eds. Proceedings of the 19th Central Hardwood Forest Conference. Newtown Square, PA: USDA Forest Service, Northern Research Station: 202–212.

Wiedenbeck, J.; Smith, K.T. 2019. Hardwood management, tree wound response, and wood product value. The Forestry Chronicle. 94(3): 292–306.

WFLC (Wildland Fire Leadership Council). 2014. The national strategy: the final phase in the development of the National Cohesive Wildland Fire Management Strategy. Washington, DC: U.S. Department of the Interior. 93 p. *https://www.forestsandrangelands.gov/documents/strategy/strategy/CSPhaseIIINationalStrategyApr2014.pdf.* (6 February 2020).