Prescribed Fire for Upland Oaks

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Practice Objective and Description

An objective of using prescribed fire is to improve the reproductive capacity of upland oaks by improving seedling establishment and reducing competition from all sources of natural regeneration (seedbank, current seed, stump sprouting, and advance reproduction). Prescribed fire is often used with other practices (mechanical or chemical) in an integrated sequence of applications within a silviculture prescription using one of the even-aged methods of regeneration to promote oak reproduction and maintain its continued dominance during stand development. Using fire as a management tool in hardwoods is complicated.

Past disturbances around the turn of the 20th century created open forest structure, lower stem density, and periodic forest openings. Disturbances such as American chestnut blight, timber harvesting, domestic animal grazing, and prescribed and wildfires promoted oak reproduction and development, and set the stage for the dominance of oak across the eastern United States following the start of fire suppression programs. Together these disturbances created conditions of higher understory light and more xeric conditions that benefited oak regeneration. Forest disturbance regimes have changed, largely by the suppression of fire, and this has led to an increase in forest density, decreasing light levels in the understory and resulting in more mesic conditions that favor shade tolerant, mesophytic species. These species, such as maples, are fierce competitors with oak reproduction, especially as site quality increases. The reduction in repetitive, low-to-moderate intensity disturbances, including fire, in mature upland hardwood forests over 50 years, has resulted in understory conditions favoring shade-tolerant oak competitors and limiting oak growth into competitive height classes, so oak can ascend to dominance in the canopy following a disturbance that releases reproduction. Without adequate numbers of competitive sizes of advance oak reproduction, maintenance of oak as a dominant species is jeopardized.

Prescribed fire can be used to achieve desired management objectives at specific times to help provide for the sustainability of oak forests. Understanding how to use fire effectively is critically important to ensure its maximum value and minimize adverse impacts. Prescribed fire is used to prepare the forest and manage for successful oak regeneration. It is useful for managing seedbed conditions for oak establishment and oak competitors by manipulating seedbank supply, tree density, and understory light levels. Prescribed fire can efficiently and effectively be used to affect seedbed conditions and manage high densities of small diameter stems in a forest. The challenge with using fire is that it is an imprecise tool; it affects areas and populations of trees and is not used to treat individual stems. Its use and effectiveness are influenced by vegetation composition and size structure, fuel types and loadings, weather, season of year, other factors that influence fire behavior, intensity and severity, and competing management goals such as timber quality, volume, and value versus ecological benefits.

Figure 1. Undisturbed upland hardwood forests have higher tree densities, creating cooler and wetter understory conditions that favor mesophytic species.

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The use of prescribed fire in the regeneration process is predicated on the fact that hardwoods sprout when above ground stems are severed or killed, and that oaks have a greater propensity to sprout following topkill than many their competitors, especially when fires occur repeatedly over time. Hardwood seedlings and saplings, including oaks, have an abundance of dormant buds located on the root collar, which are often buried in the soil and thus protected from low-to-moderate intensity fires (36). Oak seedlings preferentially allocate carbon to the root system, enhancing their capacity to sprout once topkilled (39). A tree's ability to sprout after the death or removal of the shoot can be estimated by stem size. Larger diameter seedlings, saplings, and pole sized trees readily sprout (23). In contrast, red maple, a serious and ubiquitous competitor to oak reproduction, has dormant buds that occur on the aerial portion of the stem where they are more susceptible to fire mortality. Red maple also allocates more carbohydrates to shoots than roots (66), which means they lose relatively more biomass when the shoot is killed by fire or other such disturbances such as browsing or cutting. However, red maple sprouts with abundance and can grow under full to partial shade. Red maple sprout clumps have numerous stems and dense crowns that have high photosynthetic capacity to drive sprout shoot growth, increasing diameter and bark thickness, and thus, have increased resistance to fire injury of the cambium (30). Also, a dense clump of red maple sprouts may suffer fire injury on the stems that form the perimeter of the clump, but interior stems may be protected in low intensity fires.

Figure 2. Red maple sprout clumps following dormant season prescribed fire occupy a large area of growing space.

Like red maple, other hardwood species, such as sassafras, sweetgum, and yellow-poplar, respond to topkill by sprouting, at least initially. It normally takes repeated, frequent fire to see a difference in mortality among species. Using fire to preferentially favor one sprouting species over another has provided inconsistent results due to differences in prescribed fires and stand conditions among sites. Such conditions could include varying weather conditions during a burn, fuel loading and fuel bed conditions, fire ignition method and fire type, fire behavior, fire intensity and duration, initial size structure of a species, season of burning, number and frequency of fires, and factors that affect advance reproduction growth between fires, including overstory density, initial size of stems, species shade tolerances, and growth potentials.

When to Apply

The key to successful oak regeneration is having an abundance of large, competitive advance reproduction in the stand before the final regeneration harvest that releases all the reproduction. This may take decades to develop, especially if there are few to no oak advance reproduction stems in the stand, and there is an abundance of competing species in the midstory and understory. If oak advance reproduction is lacking in the understory, then it can be established using natural regeneration, if there are sufficient acorn-producing trees in the stand. Establishment can be facilitated in some stands using soil scarification after an abundant acorn crop, or hand planting of acorns (see Soil Scarification Guidelines publication). While underplanting of seedlings can be done, results have been mixed and research has not provided enough consistent information to develop guidelines for this practice. Deep leaf litter (> 2 inches) can be a barrier to acorn germination and seed establishment (13) (62). Prescribed fire is a good tool to reduce the depth of litter layers as a site preparation treatment (56). Oaks are periodic good seed producers, with good seed crops every two to four or more years depending on the species. Hence, there is a chance that litter will accumulate rapidly over four years, necessitating a follow-up prescribed fire. However, once acorns are on the ground, prescribed fire should not be used because it causes high seed mortality. Additional applications of fire should occur only after oak seedlings are sufficiently large with a well-developed root system, which is promoted by assuring there is adequate light (30 to 50% of full sunlight) in the understory.

Figure 3. Low-intensity prescribed fire consumes leaves and small twigs and temporarily reduces litter depth.

Among the many factors that complicate the timing of prescribed fire such as management and resource limitations and weather conditions, the high species diversity in hardwood forests imposes complex ecological factors that must be considered. For example, a conundrum of using dormant season fire is that red maple produces and drops seed in the late spring. If the fire is done prior to red maple seed drop, such as the commonly employed late winter or early spring fires, bare mineral soil conditions favorable to red maple germination may be created, to the detriment of the goal of using fire to reduce oak reproduction competition. Timing fire to physiological functions, including seed production and leaf out, is complicated in hardwood systems because high species diversity results in a range of months for seed and leaf production. On average, species with diffuse porous stems including maples, cherries, and yellow-poplar produce leaves earlier in the spring than ring porous species, including oaks, hickories, and ashes.

Figure 4. Dense understory and midstory suitable for burning; fire will reduce the vegetation jumble and facilitate a more efficient foliar herbicide treatment.

Prescribed fire applied prior to establishment of abundant oak advance reproduction can also be used to lower the regeneration potential of competing species. Prescribed fire may reduce the seed supply of competing species stored in the forest floor. Or it may stimulate germination of certain species. Young germinants then would be susceptible to mortality by a second fire. If the species were shade intolerant, their growth would be minimal under the canopy of a fully stocked forest. Prescribed fires can reduce the density of fire-sensitive species in the midstory and understory, or it may reduce the height structure by causing topkill of midstory stems. Low intensity fires, typical of prescribed burning, are often able to topkill hardwood stems up to about 4 inches in diameter in many situations. Many of these stems will sprout after the initial fire, but repeated burning, especially under a full canopy, may reduce their density by mortality. Annual burning, especially in the summer, over 10 or more years may eliminate all advance reproduction, though oaks are some of the most persistent species (6) (26) (28) (38) (47) (60). Sprouts are also subject to increased browsing by wildlife and livestock, which can be a part of vegetation management. New sprouts are also more readily controlled by herbicide applications.

If a stand is in a condition in which the understory and midstory are overstocked with tall, undesirable trees, prescribed fire can be used to reset the conditions. In these stands, the undesirable vegetation is too tall or too numerous to treat with herbicide (either by spraying or by injection), and a burn, or several burns, will topkill most smaller-stemmed trees. The resprouts will be better positioned for herbicide treatment. Selectively applying an herbicide at this time facilitates moving the stand towards desired species, oaks in particular. Combining prescribed fire with other practices is often a good strategy for controlling competing vegetation. Once enough oak seedlings are established as advance reproduction, fire cessation is necessary because fire can cause high mortality in young, small oak seedlings. Midstory removal and the shelterwood method are often used to increase light in the understory and promote the growth of small oak advance reproduction. Combining fire with stand density management by thinning or using the shelterwood method is a solid approach to promoting oak advance reproduction. See other guides on midstory management and the shelterwood method.

Figure 5. A mix of desired and undesired species sprout in the understory after shelterwood overstory treatment.

Once adequate densities of competitive oak advance reproduction exist to meet management objectives, then prescribed fire can be used as a treatment for release. Adequate densities depend on management goals and site characteristics; in general, more competitive oak seedlings are required on higher quality sites. Fire coupled with other regeneration methods may be used to create these conditions, which are aimed at increasing understory light to grow and recruit advance oak reproduction. Hardwood reproduction (<4 inches DBH) of all species will likely be topkilled by a prescribed fire. Fire can be used to reduce the density of competing species in the understory and midstory, which will increase light levels to 10-15 % of full sunlight under hardwood overstories and slightly higher under pine canopies. Depending on the size of the midstory stems, multiple burns may be required to topkill the larger stems. Oak reproduction (large and numerous) should be able to survive intact or persist via vigorous sprouting in these understory conditions to increase in relative abundance and dominance among the reproduction cohort. Resprouting can be especially vigorous on more highly productive sites, creating conditions of low shade in the understory that may further inhibit recruitment of any new seedlings or nonsprouting species (20). One dormant-season fire commonly reduces the midstory density but causes increases in understory density as many topkilled stems will resprout, and most prescribed fires do not affect overstory trees enough to cause large openings in the canopy (12) (43). An exception to this would be if conditions allow for an extremely hot fire applied at a time when oaks are still dormant but competing hardwoods are emerging from dormancy (15). Repeated fires every three to five years over 10 years beneath an intact canopy are sometimes not enough of a disturbance to favor oak reproduction over other species (32) (34).

In stands where adequate reproduction exists, fire three to five years following a shelterwood establishment harvest may reduce competition and better position oak resprouts to then be recruited to the next canopy layer (11) (17) (22). Residual basal areas will range from 50 to 80 square feet and slash will have to be managed to minimize damage to residual trees. The delay of fire of three to five years allows oaks to load carbohydrates to root reserves and better positions them to vigorously sprout post-fire. It also allows competing vegetation to respond. But if the next fire is done before the competing stems get too big, they can be topkilled by the fire. The key is to not allow the oak to become overtopped by the competing vegetation and not to let the competing stems get too big (as in initiation of stem exclusion stage, or >4-inch DBH). Burning annually in the summer over 10 years or longer, where possible, with higher intensity headfires may be used to greatly reduce or eliminate woody stems in the understory (28) (38) (60). The optimal burn has been reported to be a hot spring burn, when the mesophytic seedlings have expanded leaves but the oaks remain dormant; this will vary by location, elevation, and year (15).

Common Examples of Where the Practice is Applied
Prescribed fire to promote oak reproduction is part of a sequence of prescriptions applied to mature upland hardwood-pine forests throughout the eastern US. Drier sites, including ridges, upper slopes and south-facing slopes have greater natural canopy openness and higher intensity fires (35). Fires on drier sites result in greater declines of red maple and other competitors, and higher densities of oaks and hickories compared to mesic sites (1) (2) (25) (33). Mesic sites are more challenging to manage for oak, because the diversity of competing species is higher and competition is more intense on higher productivity sites, thus more frequent and intensive management is needed to sustain oak in these systems.
If oak advance reproduction is absent but there are mature oak trees in the overstory, fire can be used to reduce the litter layer to promote oak seedling establishment following a good acorn crop (56). In addition, the fire can be used to reduce density of competing species in the midstory and understory. It may take three dormant-season fires or more over 10 years to reduce the midstory when stems are initially larger. Dormant season burning at intervals of two to three years resulted in greater fire intensities than annual burns, thus, opening stand structure to a greater extent by causing higher mortality in the midstory (6) (12) (32) (52) (59) (61). Alternatively, larger trees that need to be removed can be treated with herbicides. However, light levels in the understory should not be raised too high (>15% of full sunlight) until oak seedlings are established and ready for release; substantially increasing light before then only releases the competing vegetation. Fire should not be used after acorn drop, because it can kill most acorns lying on the surface or mixed in the litter. Acorns buried in the soil are protected from the fire. Using fire to remove interfering vegetation at this stage is not recommended, because newly established oaks are not large enough to sprout vigorously once topkilled.

If oak advance reproduction is present in sufficient numbers but is small (<12 inches tall, <0.25 inches in ground diameter) and noncompetitive, a shelterwood establishment cut is needed (see shelterwood section in this guide) to increase light to oak reproduction. This often includes removal of the midstory, which can be done by prescribed burning or by using mechanical or chemical treatments. Pre-harvest burning must be timed along with the establishment of oak advance reproduction to avoid causing mortality in small oak seedlings, especially new germinants. Post-harvest burning may be considered a couple of years following this initial harvest depending on the status of the oak reproduction and its competitors. The harvest will release the oak reproduction for several years before competing vegetation begins to suppress it. During this release, oak seedlings and sprouts can grow and increase in root size/mass. This increases oaks' ability to survive fire and sprout vigorously after burning. Oaks must be kept in a free-to-grow position in the developing regeneration canopy. Timing fire in the late spring when mesophytic competitors are leafing but oaks remain dormant is ideal, but often difficult to meet.

Multiple fires following overstory reduction has shown mixed results due to site factors that impact reproduction response and variations in the application of fire (12) (33) (37) (43). One of the most confounding results from prescribed fire studies is the variable effect on red maple competition, with some finding red maple dominance persisted in the sapling layer after thinning and repeated dormant season fires (6) (52) (61), while others showed multiple fires reduced red maple density (7) (27) (32) (33). These disparate results are due to differences in site characteristics and the initial status of the reproduction cohort as well as realities in timing the prescribed fires. In contemporary upland hardwood forests that have not been disturbed for 50 years or more, species structure and composition have shifted, with more vigorous and ubiquitous mesophytic species, including red maple, sassafras, sweetgum, and black gum. Just as advanced reproduction of oaks must be cultured prior to the final regeneration harvest, control of the undesirable competing trees is also recommended. The reality of getting a prescribed fire done within the perfect prescription window that includes weather, fuels, and tree physiology is limited, and most burning occurs when weather condition parameters are met. Timing implementation to the physiological status of vegetation is complicated and perhaps impractical.

Examples of Conditions or Situations that Limit Effectiveness

Prescribed fire, like most forestry practices, is subject to several potential constraints including abiding by local laws and regulations, landowner liabilities related to fire escapes, smoke management issues, social acceptance, capability to conduct burns, and weather and fuel conditions. Prescribing fire requires detailed burn plans that address these constraints, as well as those associated with achieving management goals and objectives for the burn. Currently, most prescribed fire is done in the dormant season of winter to late spring, and within a limited range of environmental, weather and fuel conditions, and acceptable fire behavior that limits the "burn window". Collectively, these social, environmental, and management constraints can limit the number of burn days in a year or negate burning for any given year. There is some flexibility in the timing of prescribed burning to produce desired effects and accomplish forestry objectives, but delays over time can lead to irretrievably missed opportunities or problems with accumulated workloads, especially on large ownerships.

Figure 6. Fire damage to the lower stem of a large white oak following prescribed fire.

Prescribed fire can kill a significant proportion of the acorn crop and first-year oak seedlings. Burning immediately after a good acorn crop and initial seedling establishment is not recommended. However, the purposes for burning are certainly present over the long-term, and thus, there is adequate time to plan burns before a good acorn crop and when a young seedling cohort establishes. Or likewise, fire can be planned to control competing vegetation after oak seedlings are developed and have high sprouting potential and vigor following a fire. Such an example is the use of fire either before oak establishment, aka, site preparation burning, or after oak release by the shelterwood method when prescribed fire is used to control competing vegetation and promote oak dominance in regeneration (12) (14).

Young stands reaching canopy closure and entering the stem exclusion stage of development are not good candidates for prescribed burning. There may be a need to release crop trees (see the guide on that procedure) or thin to reduce stand density to enhance growth and control species composition, but fire is a difficult tool to use in this situation. First, the amount of fine fuels in these dense stands is very low in the heavy shade and this limits fire spread and reduces the number of good burning days in a year. Second, fire is indiscriminate and opportunistic in which trees are removed or injured when trees are sapling to small pole sized. Managers have little control over extent of thinning or spatial arrangement of trees when using prescribed fire. Finally, fire-injured trees will remain in the stand for decades and this gives time for decay to develop in the lower portion of the stem. Mechanical or chemical methods of thinning individual trees are superior to prescribed burning in young sapling pole sized stands.

When fire is applied to older, mature stands, care must be taken to minimize injury to residual trees, especially those that may remain in the stand for more than 15 years. Although most large overstory trees are uninjured and undamaged from low intensity dormant season prescribed fires (16) (41) (53) (57), there is potential to cause damage that may include outright mortality or wounding of the lower bole that leads to loss of volume and value to the most valuable part of the tree. Research has found that mortality of merchantable overstory trees is minimal under a regime of repeated low intensity dormant season fires (34) (53). Also, loss of value and volume to bole wounding and damage by decay and degrade are minimal if the damaged trees are harvested within 10 to 15 years of the fire (41) (42). Losses in value and volume are higher in red oak species (10%-13% value loss over 15-25 years) than white oak species (2%-4% value loss over 25 years) (41) (42). Burning after thinning or shelterwood harvesting can cause severe damage to residual trees if slash is left against trees, but removal of slash within a 3-foot radius of the bole eliminated fire-injury to the bole of oaks (16). Where high value timber is present in the stand, individual trees can be protected from fire injury by the removal of larger slash and fine fuels from around the base of the tree. The number of veneer and stave bolt trees per acre in a stand are normally few and they can be identified and protected before burning. Although results are inconsistent in prescribed fire effects on tree diameter growth, it is commonly observed that such fires reduce diameter growth, thus increasing the number of rings per inch that is important in the veneer and cooperage industries for grain appearance and water tightness, respectively. As always, there are alternative chemical and mechanical methods for managing vegetation that can be used in place of prescribed fire if the fear of fire injury is high.

Post-implementation Conditions
A single prescribed fire done in the spring usually consumes the leaf litter and may reduce the duff by up to 50%, exposing mineral soil on only 2%-4% of the area (5). Frequent fires (e.g., four in six years) increase duff reduction to over 60% and expose more mineral soil (up to 25% for example). Under a fully stocked hardwood canopy, litter accumulates rapidly after the last fire such that four years after a burn, as much as 75% of the original litter mass has returned (54). If deep litter (e.g., >2 inches deep) is inhibiting oak seedling establishment, then prescribed fire needs to be repeated periodically until a good acorn crop occurs.

Low intensity dormant season fires often topkill hardwood trees and shrubs of any species below a diameter of about 4 inches DBH (4). Thus, there is often a substantial reduction in midstory density depending on the size structure of that canopy layer. Many of these stems are likely to resprout after the first fire, and this initially results in increased density of the understory woody vegetation. But as fire continues to be applied frequently, seedling sprout density can be reduced. These types of fires have little effect on overstory density even when frequently applied over the long-term, with about <5% reduction in overstory basal area (34). As fire intensity increases to moderate levels (>4-foot average flame lengths), overstory mortality may increase, especially where thinning or logging slash occurs around trees.

Practice Use Within a Silvicultural Framework
Prescribed fire used as a treatment in the regeneration process is most often applied in fully stocked sawtimber stands that are within 10 to 20 years of rotation age, because preparing for good oak regeneration and reducing competing vegetation may take that long. Consideration must be given to the status of the oak advance reproduction and competing vegetation. If no oak advance reproduction is present, then prescribed fire may be used to prepare the site and stand for oak establishment and early growth. Where deep litter is a concern for oak germination and seedling establishment, then prescribed fire should be done prior to the dispersal of a good acorn crop. If the stand has high densities of undesirable midstory and understory vegetation, then prescribed fire can be used without harvesting to reduce or eliminate the mid-story canopy layer and decrease the density and regeneration potential of understory vegetation. If adequate (abundant large stems) oak advance reproduction exists, prescribed fire can be used three to five years following a shelterwood establishment cut to reduce competing stems. Prescribed fire can be used to benefit the oak regeneration process after any thinning or shelterwood harvesting, including the final removal of the shelterwood as long as the oak reproduction has a high probability of persisting after burning through sprouting. A fire-free period is then needed to allow oak to ascend to sapling/midstory size classes.

Data and Observations
Information is required to determine if the stand has:

- Adequate stocking of competitive advance oak reproduction.
- Adequate stocking of merchantable trees, by species, sizes, and grade, that can support two commercial harvests; the initial removal of approximately 50% of the stand's basal area and a subsequent second harvest of the remaining merchantable stems.

<u>Overstory</u>
This practice requires a well-timed sequence of events, with adequate no-treatment periods interspersed to allow for growth and assessment. Most prescribed fire for regeneration will be done in conjunction with some harvesting. An initial harvest to a target residual basal area is needed to open the stand, allowing oak reproduction to recruit into larger size classes. If interfering vegetation is severe, prescribed fire can be used to reduce stem densities. The second removal can be a complete removal of all merchantable stems, or a partial removal that retains stems of interest, such as those for aesthetics or acorn production for wildlife. The second entry typically occurs 10 to 20 years after the initial removal and is dependent on individual stand and site characteristics. Because most stands suitable for a shelterwood treatment are mature and fully or over stocked, the initial harvest should be economical while leaving enough desired residual stems for a second harvest. The key is to ensure residual trees will meet future merchantability needs and can withstand scarring from fire with minimal degrade. Data must assess the stand's current and residual merchantability. Plot-level data or a total inventory, if it is customary to do so for a timber sale, should be collected to provide information on both current and future volume and value. Tally data of dominant, co-dominant, and strong intermediate crown class trees should include species, diameter, volume, and current and future merchantability/value. While estimating current merchantability involves the use of local merchantability standards, future merchantability requires a projected merchantability/value. The latter can be accomplished by using either the current merchantability, assuming, at a minimum, it will be present 10 to 20 years in the future, or projecting merchantability increases.

<u>Reproduction</u>
To justify this practice the stand must have the potential to regenerate upland oaks. The regeneration potential for oak requires:

- Acorn Production- an overstory of desired oaks that has the capacity to produce acorns continuously or periodically. In a stand of mixed oak species, there is normally acorn production yearly, with some years considered mast years (high acorn production) (19). If deep litter is a deterrent to oak germination, prescribed fire prior to initiating regeneration will reduce litter but should not be used after acorn drop once the regeneration process commences.

- Advance Reproduction- advance oak reproduction that has the capacity to produce a dominant or co-dominant stem upon release from the regeneration cohort. Understory oaks are best positioned to respond to competition and release if they have an initial height >3 to 4 feet tall (49). Providing quantitative estimates of successful advance reproduction stocking can be difficult. Generally, to ensure oak recruitment into future dominant canopy positions, oak reproduction densities should be 100-400 or more stems per acre (50) of stems 3 to 4 feet tall. About 120 codominant oaks are needed in a 20-year-old stand to achieve 50% oak stocking at stand maturity (14) (51) (63). For oaks to reach this size and density, a fire-free period of 10-30 years is necessary (12).
- Sprouting Capacity- stump sprouting capacity of sapling and pole sized oak trees (stump sprouters). Stump sprouts originating from harvested trees are another potential source of oak reproduction. Sprouting capacity is species- and age-dependent (see table 5) (24) (65). White oaks should generally be less than 30 to 40 years old, while red oak can maintain sprouting capacity to 60 to 80 years (40). After 25 years, dominance of sprouts from cut oak trees was highest for small trees that were 4 to 6 inches DBH (64) (65). Generally, if there are more than 20 to 30 saplings (2 to 6 inch DBH) or pole sized (6 to 10 inch DBH) trees per acre that can be cut and left to stump sprout, the stand can maintain an oak presence in the regenerating age class.
- Sprouting potential from interfering vegetation will be stimulated by fire topkill and should be assessed. Most southern upland hardwood forest understories are dominated by red maple; response of red maple thus dominates observations and study results. Blackgum, sweetgum, sassafras, and sourwood will all sprout extensively when topkilled. Timing of fire will dictate long-term impact to resprouting fecundity.

On more xeric sites where oaks are dominant across size classes, assessment of advance reproduction and potential contribution by stump sprouting may not be required. On most sites, data collected from fixed-area 0.01-acre plots are recommended to tally and determine size and numbers of oak advance reproduction. Fixed area plots or variable area plots (prism plot sampling using a 5 basal area factor prism) can be used to determine the number per acre of sapling and pole sized oaks. For both advance reproduction and stump sprouting potential, a count of acceptable oak stems (those >3-4 feet tall) by species is adequate for use in determining oak stocking. Note of potential undesirable and competing sprouting stems should be taken.

<u>Interfering Vegetation</u>

Competing vegetation can pose as barriers to successful oak regeneration by limiting available light and growing space. Prescribed fire will affect the entire reproduction cohort, including non-desirable species. If there are an abundance of shade-tolerant stems in the understory and midstory, additional treatments are needed to maintain oak development and recruitment. A target reduction of the midstory by herbicide will selectively eliminate competing vegetation and their sprouting potential negated. Assessment of interfering vegetation using a fixed or variable area plot to determine the density and basal area of potential competing stems, including residual trees, will guide a treatment decision. This assessment will provide information needed for practices related to site preparation associated with the harvest, such as treating cut stumps. If red maple is present in the stand, elimination is warranted prior to using fire unless fire intensity and timing can be controlled.

Data needed to develop a prescription can be divided into categories to help facilitate efficient data collection:

General Observations of the stand:

- Presence of invasive species: abundance: high, moderate, low, none
- Distribution of invasive species: infrequent, moderate, widespread
- Distribution of red maple or other sprouters: high, moderate, low, none
- Evidence of deer browsing: high, moderate, low, none
- Acorn production capacity: low, moderate, high
- Site factors: aspect, slope, site index, litter depth, burn history

Forest Inventory to characterize the overstory, midstory and understory:

- Overstory: species composition, basal area, trees per acre, average diameter
- Midstory: species composition, density
- Understory: species composition, density, size (height or basal diameter classes)
- Sprouting potential: species composition and sizes

Observations for Prescribed Fire:

- Fuel conditions: types, loading, continuity, arrangement, exposure, non-target fuels
- Fuel models (3) to predict fire behavior
- Fuel Photo Guides (10) (21)
- Fuel loading by time lag classes (29) along transects (18)
- Flame heights for release: >2 feet, rate of spread 3-7 feet per minute
- Surrounding area: smoke management concerns: schools, nursing homes, hospitals, airports, residential areas, roads

On site:
- power lines
- roads
- buildings

Monitoring:
- Repeat forest inventory, assess oak status and competition
- Note spread of invasive species
- Indicators of success: increase in relative proportion of large oak reproduction, reduction in density (by size) of competing vegetation, status of invasive species

Planning and Marking
Unlike many other practices, the implementation and marking associated with prescribed burning is highly variable and must be carried out according to local and state guidelines and regulations. The following provides information on implementation based on stand condition.

Mature oak forest but no oak or few oak in understory and understory occupied by undesirable vegetation:
- stand at beginning of oak regeneration process
- oak status unknown due to competing vegetation, including non-native invasive species
- site preparation burns most likely in dormant season, later season best
- assess sprouting response after burn and treat small sprouts with herbicide
- assess oak reproduction response after burn; take care to not treat with herbicide
- move to mature oaks forest but no oak or few oak in understory stage (see below)

Mature oak forest but no oak or few oak in understory:
- stand at beginning of oak regeneration process
- site preparation burns most likely in dormant season
- reduce dense shade and thick litter layer (90% litter consumed)
- create conditions favorable to acorn germination and seedling establishment
- don't burn after acorns drop
- keep an eye on competitors, especially new red maple seedlings
- monitor for oak reproduction establishment; if none, can consider additional burning to reduce midstory and competing understory and leaf litter and/or artificial reproduction

Oak forest with small abundant oak advance reproduction:
- stand at the end of oak regeneration process
- burn will follow first stage shelterwood to 45-65 square feet of residual basal area
- before burn, ensure oak reproduction is large enough (0.5-inch root collar diameter)
- before burn, ensure oak reproduction is dense enough (more needed on better sites)
- monitor oak reproduction, if starting to get suppressed (overtopped) then spring burn
- may want to manage slash (remove) around base of valuable residual trees
- burn to kill new germinants, favor oak (still dormant) over mesophytic species (leafed out)
- may have to burn when feasible under most favorable conditions
- repeat periodic burning as oak gets suppressed until oak "big enough" to release
- final removal of shelterwood based on size of oak; follow up with prescribed fire if needed to control competition and if oak reproduction is large enough to adequately sprout
- monitor, repeat prescribed fire periodically to continue promoting oak dominance
- stop fire so oaks can recruit into overstory

Oak forest desired but already regenerated:
- post-harvest burning
- oak height within 1-2 feet of competitors
- fire intent to reduce competitors and favor oak resprouting
- spring burn when mesophytic species are 50% leafed out and oaks are still dormant
- fire will be more intense due to higher fuel loads
- monitor response; may repeat fire or use herbicide on mesophytic sprouts
- stop fire to recruit oaks into overstory

Site Considerations
On higher productivity sites (>70 oak SI), it becomes increasingly harder to promote oak regeneration. It is not impossible but will require more frequent and, in some cases, more intense applications of practices, often in combination, to control competing vegetation. Prescribed fire is an efficient tool for controlling or reducing high densities of smaller stems (<4 inch DBH) of competing species over larger areas, but it must be applied repeatedly to maintain oak reproduction in positions

of dominance during regeneration. There are few site factors that limit the application of prescribed fire as long as there are fuels to ignite and carry fire at desired intensity over the stand. Site topography, fuels, and weather will influence the way prescribed fires are ignited and managed.

Barriers to Success

Barriers for the effective use of this practice include both social and biological elements as discussed below, and issues associated with residual stand damage as discussed in Section 6.

Social constraints

Fire is prescribed to achieve specific management goals under controlled conditions that address human health and safety, and ecological, economic, legal, and other concerns and constraints. Its use is influenced by site, stand, fuels, weather, and social conditions. Weather is an important constraint, because extreme fire behavior is to be avoided. Thus, the weather defines the burning window, which can become a major constraint in the use of fire throughout the year. Concerns and limitations imposed by threatened and endangered species may limit fire use, as they do any forestry practice. Regulatory and liability laws regarding fire may limit or negate the use of fire. Risk to landowners and managers of escaped fire is real because of the potential for substantial damage to property as well as human injury or death. Smoke can negatively impact public health or impair visibility affecting transportation. State laws may require certification and specialized training with experience to use prescribed fire. Certified prescribed burning managers are often held to higher standards of care and have legal incentives such as limitation of liability for escaped fire (31). Prescribed fire has costs related to planning and implementation. Hiring a certified prescribed burner, using cost-share programs provided by state agencies, or becoming certified as a landowner are all viable options to reduce uncertainties and risk.

Nonnative Species Constraints

Information on the response of non-native invasive species (NNIS) to fire is sparse. Many reported results are often after a single dormant season prescribed fire, so that the response under growing season fires or multiple dormant season fires has not been well documented. Characterizing response must be related to the biology and ecology of a given species, coupled with site characteristics and burning regime. Many NNIS do respond vigorously to disturbance and more open stand conditions and are adapted to fire. NNIS may change fuel properties and fire behavior (8), resulting in increased flammability and fuel continuity. Because of their adaptations to persist through a fire, prescribed fire must often be repeated frequently to reduce root carbohydrates and sprouting vigor; timed so fire behavior is as hot as possible; timed when target species are most vulnerable, i.e. at leaf expansion (48); or combined with other vegetation control methods such as herbicides or mowing. Designing fire regimes to promote desired species is required while dealing with NNIS in and around the project site. If NNIS are a known problem in a stand, it is recommended that chemical and/or mechanical treatments be used to reduce their densities prior to any other disturbance (46).

Two examples of the interaction of fire and NNIS follows. Tree-of-heaven seedlings and saplings may be topkilled by one dormant-season fire but are able to readily sprout along with new germinants from seed. The new seedlings are not competitive with the faster growing woody reproduction that suppresses and shades out the young tree-of-heaven (45). They also found that herbicide treatment with one prescribed fire killed most trees and saplings, with no resprouting four years later (45). To reduce Chinese tallow tree in a maritime forest, a sequence of treatments, starting with understory mastication to reduce woody stem density, followed by a foliar treatment and then by a growing season fire, reduced densities of tallow tree reproduction (44). A comprehensive synthesis of available information on the interactions between fire and NNIS was done by the U.S. Department of Agriculture Forest Service's Fire Effects Information System (58).

Monitoring

Continuing assessment of reproduction and residual tree status is critical for timing actions and adjusting treatments. Because fire can be such a blunt tool, monitoring of desired and undesired reproduction should be done systematically across the entire stand. Timing of monitoring is also important, as windows for recruitment of reproduction and for removal of damaged timber is limited.

Pre-fire (or implementation)

- Assess: The size and number of desired oak reproduction and undesired competing vegetation
- How: A fixed-radius circular plot of 1/100 acre (11.8-foot radius); at least one plot per acre is recommended; tally trees and other vegetation by species and height classes using 2-foot height classes up to 6 feet
- Action 1: If oaks are mostly short (<2 feet tall), and/or overtopped by other species, release by some other means besides fire (herbicide is best, as it prevents resprouting); if oaks are few, allow for a mast crop and then reassess; can remove midstory in preparation for new seedling establishment and recruitment
- Action 2: Survey over the next one to five years to determine oak recruitment to midstory status
- Action 3: If oak is numerous and in a competitive position, fire can be used with or without a partial harvest to re-duced competition and increase light to understory oaks

Directly post-fire (or implementation)

- Assess: Cursory check of conditions; ocular assessment of burn continuity and remaining fuels

- How: Use fixed radius regeneration plot locations
- Action 1: If patchy burn conditions exist, consider if fuel loads and conditions would warrant another fire immediately or during the following dormant season

10-15 years post-fire

- Assess: Residual tree damage
- How: a fixed-radius circular plot of 1/20 acre (26.4-foot radius), 1/10 acre (37.2-foot radius) or 1/5 acre (52.7-foot radius); for all trees 6 inches DBH and larger, determine tree status (dead or alive), wound numbers and sizes; fire char height; epicormic branching; bark sloughing or other signs of decreased vigor
- Action: Remove damaged sawtimber trees if possible to prevent volume and value loss. Volume and value loss increases over time since fire injury and with increasing size of the fire wound. White oak species experience significantly less loss in volume and value than do red oak species and maples (41). Fire scars less than 20 inches tall in red oak species result in little value (10%-13%) and volume (2.4%) loss after multiple burns over 15 years (42). Wounds from prescribed fire in white oak that are less than 15 inches wide can close within five years on average (55). Therefore, if opportunities for commercial harvesting occur within 15 years of prescribed burning, preference would be to remove merchantable red oak species and maples, given other silvicultural objectives and prescription guidelines.

Costs

Each state has its own requirements and services related to prescribed fire. Most states require a prescribed burn plan that may be offered as a 'free' service and the supervision of a certified prescribed burn manager. Certification is required to reduce the liability related to prescribed burning and certified burners can obtain burn permits. In general, states provide private landowners with prescribed burning services at a cost to the landowner. Some states also have private organizations and individuals who provide prescribed burning services. Landowners can become certified prescribed burners. Certification requires 16-32 hours of in-house training, the passing of a written test, and experience requirements that may include years of prescribed fire work and/or service as the lead for a certain number of prescribed fires. Some states charge a minimal service fee between $400 and $600 for each prescribed burn, in addition to equipment and implementation fees. Please see your local state forestry agency for additional fees associated with prescribed fire practices. Additional cost associated with using prescribed fire to release desired oak reproduction may include those associated with a timber harvest and herbicide treatment for non-native invasive species or other interfering vegetation.

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White Oak

- Acorns of species in the white oak group exhibit non-dormancy and germinate in the fall, increasing new germinant susceptibility to dormant-season fires.
- White oak seedlings can persist in the understory for long periods of time, and they invest growth into roots. While vigorous rooting may enhance their ability to remain alive, residence time in these low light environments can stymie response to release, as seedlings may be resource compromised.

- White oak seedlings from acorns had the slowest growth for years compared to other oaks (9).
- White oak stump sprouts had the lowest probability of surviving to age 5 compared to other upland oaks, so relying on stump sprouts to contribute to the reproduction must take this into account (23).

NRCS Conservation Practices

- Core Conservation Practice: Prescribed Burning (Code 338)
- Supporting Conservation Practice: Firebreak (Code 395)

"Caring for Your White Oak Woods" USDA Natural Resources Conservation Service, 2p.

The selection of prescriptions included in the Upland Oak and White Oak Silviculture Practice Series were established through consultation with silviculture researchers and state forestry management personnel across the region. The peer reviewed individual silvicultural prescriptions were authored by research silviculturists with significant experience in oak management. This series was designed to provide silvicultural guidelines that be used by practitioners and managers along with their knowledge and familiarity with local stand conditions, markets, and contractor expertise to make decision enhancing regeneration, recruitment, and growth and development of upland oaks with a special emphasis on white oak. Other publications in the Series and information on white oak sustainability can be obtained at www.ukforestry.org and www.whiteoakinitiative.org.

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