Evaluating the Applicability of the Shelterwood-Burn Technique for Regenerating the Mixed-Oak Forests of the Allegheny National Forest

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ABSTRACT.—We evaluated the usefulness of the shelterwood-burn technique for regenerating upland mixed-oak (*Quercus* spp.) stands on the Allegheny National Forest of northwestern Pennsylvania. Two mid-spring prescribed fires were conducted in four upland mixed-oak stands that had been partly harvested due to defoliation-mediated mortality and subsequent salvage logging. Overall, the technique performed reasonably well. Before the burns, red maple (*Acer rubrum*) and sweet birch (*Betula lenta*) reproduction dominated the stands in terms of stem density and height. However, two fires conducted 3 years apart killed many of the birch and maple seedlings, creating a seedling pool with a substantial oak component. Additionally, interspecific heights among the seedlings were approximately equal. If these promising trends continue through the final harvest to crown closure of the new stand, then the shelterwood-burn technique will have been shown to be a viable silvicultural method for the Allegheny National Forest.

INTRODUCTION

Throughout the eastern United States, natural resource professionals and the general public highly value upland, mixed-oak (*Quercus* spp.) forests for the multitude of ecological and economic benefits that they supply to society. The forest products sector uses oak extensively; the wood is made into cabinetry, flooring, furniture, construction lumber, pallets, paneling, and specialty items such as whiskey barrels. Oak forests are renowned as wildlife habitat as they provide food and shelter for a variety of species ranging from insects to large mammals (McShea and Healy 2002). Additionally, oak forests offer watershed protection, supply high-quality water resources, and contribute to landscape aesthetics and diversity. Finally, the longevity of the oak trees means they can provide these goods and services for decades. Because of these diverse values, many natural resource managers try to maintain mixed-oak forests on the landscape through sustainable management practices. However, regenerating mixed-oak forests is a daunting task as the regeneration process is slow and vulnerable to numerous problems, especially on intermediate to high-quality sites where competition from mesophytic hardwoods is intense. The Allegheny National Forest (ANF) in northwestern Pennsylvania epitomizes this conundrum of high-value oak and its regeneration challenges. While only about 15 percent of the ANF's 533,000 acres are classified as upland mixed-oak forests, they are prized by the local communities and sustaining them is an objective of current and past forest management plans (Allegheny National Forest 1986, 2007). However, forest managers seeking to do so are confronted with multiple obstacles such as interfering understory vegetation, highly competitive mesophytic hardwood species, and chronic whitetail deer (*Odocoileus virginianus*) browsing. Because the current upland mixed-oak forests exist, in part, due to past fires (Marquis 1975), the ANF became interested in the early 2000s in testing the applicability of the shelterwood-burn technique to overcome some of the oak regeneration obstacles.

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The shelterwood-burn technique originated in the Piedmont region of Virginia in the late 1990s to address red maple (*Acer rubrum*) and yellow-poplar (*Liriodendron tulipifera*) replacing upland mixed-oaks when they were harvested (Brose et al. 1999a, 1999b). It consists of a two-step shelterwood sequence with a hot mid-spring fire applied between the two harvests. The first harvest removes the midstory strata and creates about 50 percent open canopy, thereby allowing ample sunlight to reach the oak seedlings so they can quickly develop their root systems. After 4 to 7 years, the oak seedlings have large root systems and the mesophytic hardwoods are beginning to overtop the oaks. A hot, mid-spring fire occurs during leaf expansion of the understory strata and topkills all of the seedlings and forces the rootstocks to sprout. The oak reproduction experiences less mortality and has accelerated growth relative to the mesophytic seedlings, resulting in an improved competitive position for the oaks relative to the other species. The second harvest usually occurs within 5 years of the prescribed fire.

In late 2000, the ANF approached the Irvine Forestry Sciences Lab of the Northeastern Research Station (now the Northern Research Station) about an administrative study to test whether the shelterwood-burn technique could be used to overcome the competing and interfering vegetation obstacles to sustaining upland mixed-oak forests in the local area. Of particular concern were the responses of keystone oak species (northern red [*Quercus rubra*], black (*Q. velutina*), chestnut (*Q. montana*), and white (*Q. alba*)] and the primary competitors, red maple and sweet birch (*Betula lenta*). Also of concern were how important associate species such as black cherry (*Prunus serotina*), cucumber tree (*Magnolia acuminata*), and serviceberry (*Amalanchier alnifolia*) would respond to the technique, as these had not been extensively examined in prescribed fire studies. The purpose of this paper is to report the results of that administrative study.

METHODS

This study was conducted from 2001 to 2010 in four upland mixed-oak stands located on the Bradford Ranger District of the ANF. Each stand was dominated by northern red oak with lesser amounts of black, chestnut, and white oak. Associate hardwood species included black cherry, cucumber tree, red maple, sweet birch, and yellow-poplar. Stand sizes ranged from 25 to 50 acres and were situated on upland benches so aspect and slope were inconsequential. Oak site index was estimated between 70 and 75 feet based on stand records. All stands were less than fully stocked (basal areas ranged from 60 to 90 square feet per acre) due to gypsy moth (*Lymantria dispar*) defoliations in the late 1980s and early 1990s and subsequent salvage harvesting of some mature oaks. Due to this disturbance, the midstory of each stand was well developed and consisted of mesophytic hardwoods, especially red maple and sweet birch. All stands had been fenced to exclude deer shortly after the salvage harvests. The fences were moderately successful; deer penetrations into the stands were a chronic problem throughout the study. Nevertheless, the understories had an abundance of herbaceous and woody vegetation including hardwood seedlings of the same species as the overstory trees.

Each of the four stands was split into two equally sized treatment blocks and each block was randomly assigned to be a spring burn or an unburned control. In each treatment, SILVAH sampling plots (Marquis et al. 1992) were systematically installed at a density of 1 plot per acre to uniformly cover the area. In summer 2002 and 2003, these plots were inventoried for basal area/density of overstory trees, percent cover of herbaceous vegetation, and density/height of hardwood seedlings less than 1-inch diameter at breast height (d.b.h.) using established procedures (Marquis et al. 1992). Inventory tallies were limited to the major tree species of the ANF. Those were as follows: American beech (*Fagus grandifolia*), black cherry, cucumber tree, northern red oak, other oaks, pin cherry (*Prunus pensylvanica*), red maple, serviceberry, sugar maple (*Acer saccharum*), sweet birch, and yellow-poplar.

Because the forest plan in existence at the time did not have prescribed fire as an acceptable silvicultural activity for mixed-oak forests, the ANF had to conduct an environmental assessment before conducting the burns. This assessment took approximately 3 years to complete, so spring 2004 was the first spring the prescribed fires could have been conducted. However, that spring was quite rainy so the burns were delayed until 2005 when weather conditions were much more favorable for conducting prescribed fires. The burn blocks in two stands were burned on May 6, 2005, and those in the other two stands were burned 3 days later on May 9, 2005. At this time, leaves of the mesophytic hardwood seedlings were approximately 50 percent expanded while the buds on the oak reproduction were only swollen. Weather conditions were measured using a belt weather kit. Recorded conditions for all burns were essentially identical; dry bulb air temperature of 70 to 75 °F, relative humidity between 20 and 30 percent, west winds less than 5 mph, clear skies, and no precipitation for at least 3 previous days. Ten-hour fuel moistures ranged from 10 to 15 percent based on a hand-held wood moisture meter. Observed fire behavior for all fires was as follows: flame lengths of 2 to 4 feet and rates-of-spread between 2 and 5 feet per minute.

All plots were re-inventoried for herbaceous vegetation, overstory trees, and seedlings in summer 2007. A second prescribed fire was conducted in each spring burn treatment block on May 7 and 11, 2008, due to the mesophytic hardwood seedlings' re-emerging dominance over the oak seedlings. At this time, the leaves of the mesophytic hardwood seedlings were approximately 50 percent expanded while the buds on the oak reproduction were swollen. Weather conditions for all burns were as follows: dry bulb air temperature of 55 to 65 °F, relative humidity between 30 and 40 percent, west winds less than 5 mph, 50 percent cloud cover, and no precipitation for at least 3 previous days. Ten-hour fuel moistures ranged from 20 to 25 percent based on a hand-held wood moisture meter. Observed fire behavior for all fires was as follows: flame lengths of 1 to 2 feet; and rates-of-spread between 1 and 3 feet per minute. All plots were re-inventoried for a third time for herbaceous vegetation, overstory trees, and seedlings in summer 2010.

The response variables for this study were density (mean stems/acre), height (mean tallest), and stocking (proportion of plots containing at least one stem) of the seedlings of the major tree species and percent cover of the herbaceous vegetation. The data were analyzed as a randomized complete block with repeated measures via Proc GLMMIX (SAS Institute 2009). Species and prescribed fire treatment (control or spring burn) were the fixed effects in the model while stand was the random block effect. Year of inventory was the repeated measure. To measure the correlation between inventories, we used an autoregressive order 1 covariance structure. Because the response variables for herbaceous cover and stocking were percentages with many large and small values, we used a beta distribution, logit link function, and the Kenward-Rogers denominator degrees of freedom method. We used the Tukey-Kramer least squares mean separation test and an alpha of 0.05 for all multiple comparisons. Residuals were examined to ensure that model assumptions were met.

RESULTS

At the beginning of the study, the four stands were quite similar to each other. Overall, they averaged about 200 trees per acre with an average d.b.h. of 9.5 inches, 94 square feet of basal area (BA), and 60 percent relative density (a measure of stocking). Of these metrics, oaks contributed 30 trees per acre (all in the main canopy) with an average d.b.h. of 19.5 inches, 57 square feet of BA, and 39 percent relative density. Conversely, mesophytic hardwoods tallied nearly 170 trees per acre (primarily in the midstory), with an average d.b.h. of 6.0 inches, 40 square feet of BA, and 20 percent relative density. Dividing each stand into two treatment areas did not result in any differences in overstory metrics among the treatment areas.

In the understory, total seedling estimates averaged slightly more than 37,000 stems per acre with no pretreatment difference between the control and spring burn treatments (Table 1). Red maple seedlings were the most abundant (≈ 11,000 per acre), about 30 percent of all seedlings. Northern red oak seedlings numbered approximately 9,660 per acre followed by black cherry (4,835) and sweet birch (3,185). Seedlings of all other species ranged from 415 (American beech) to 1,500 per acre (pin cherry).

Stocking of the seedlings reflected their abundance, with the most common species being the most widely distributed across plots (Table 2). Black cherry, northern red oak, red maple, and sweet birch occurred on more than 68 percent of the plots. Stocking of all other species ranged from 7 to 32 percent. Herbaceous ground cover ranged from 40- to 50-percent cover regardless of treatment and consisted almost entirely of ferns (bracken [*Pteridium aquilinum*], hay-scented [*Dennstaedtia punctilobula*], and New York [*Thelypteris noveboracensis*]) and various species of grasses.

The seedlings formed three height strata at the beginning of the study with no differences detected among the two treatments (Table 3). Sweet birch and pin cherry were in the first stratum with their tallest stems averaging from 9.7 to 13.2 feet. The second stratum consisted of black cherry and red maple with their tallest stems ranging from 5.1 to 7.2 feet in height. All other species were in the third stratum with their tallest stems ranging from 1.3 (northern red oak) to 3.6 (yellow-poplar) feet. In this stratum, yellow-poplar had the tallest stems and the oaks were the shortest species. The fern layer was generally as tall as or slightly taller than the shortest oak seedlings.

The first prescribed fire reduced overall seedling densities by about one-third, from 38,035 to 25,075 seedlings per acre (Table 1). Most of this reduction came in northern red oak (69 percent), other oaks (57 percent), red maple (48 percent), and sweet birch (43 percent). American beech, yellow-poplar, and miscellaneous hardwood seedling densities increased following the first prescribed fire while densities of all other tree species were relatively unchanged. Seedling densities in the control treatment also declined by 13 percent relative to pretreatment (36,050 to 31,000 stems per acre) and this decrease occurred almost entirely in the oaks. Northern red oak seedling counts dropped from 9,770 to 3,850 stems per acre (61 percent) while other oaks declined from 2,075 to 1,200 stems per acre (42 percent).

The postburn decline in red maple and sweet birch seedling densities affected their distribution among plots as stocking levels dropped from 96 to 79 percent for red maple and 68 to 54 percent for sweet birch (Table 2). Stocking levels also dropped for sugar maple from 7 to 3 percent. Conversely, stocking levels for serviceberry, yellow-poplar, and miscellaneous species increased following the first burn. For all other species stocking did not appreciably change between 2003 and 2007 nor did it change for herbaceous vegetation during the same period.

Table 1.—Densities (mean stems/acre ± 1 standard error) of hardwood seedlings by species, treatment, and year. Pretreatment year is 2003 while 2007 and 2010 are after the first and second burns, respectively. Means followed by different uppercase letters are different within that row while those followed by different lowercase letters are different within that year and treatment.

Species or group	2003	2007	2010
	Control treatment		
American beech	415 ± 50Ae	425 ± 150Af	435 ± 100Ag
Black cherry	4,275 ± 450Ab	5,275 ± 450Bb	5,400 ± 200Bb
Cucumber tree	650 ± 60Ae	760 ± 70Ae	750 ± 70Af
Northern red oak	9,770 ± 850Aa	3,850 ± 350Bc	1,950 ± 400Cd
Other oak	2,075 ± 500Ac	1,200 ± 180Bd	800 ± 200Bf
Pin cherry	575 ± 125Ae	575 ± 100Ae	230 ± 50Bg
Red maple	11,500 ± 750Aa	11,700 ± 400Aa	10,600 ± 350Aa
Sweet birch	3,465 ± 300Ab	3,615 ± 175Ac	3,540 ± 150Ac
Sugar maple	400 ± 125Ae	400 ± 125Ae	400 ± 100Ag
Serviceberry	1,075 ± 80Ad	1,150 ± 75Ad	1,025 ± 60Ae
Yellow-poplar	1,280 ± 50Ad	1,200 ± 150Ad	1,020 ± 200Ae
Miscellaneous	570 ± 75Ae	850 ± 200Be	700 ± 150Bf
Total seedlings	36,050 ± 4000A	31,000 ± 3500AB	26,850 ± 2,500B
	Spring burn treatment		
American beech	600 ± 75Ae	1,425 ± 150Bd	925 ± 100Cf
Black cherry	5,400 ± 500Ab	5,425 ± 450Aa	4,550 ± 200Ba
Cucumber tree	775 ± 75Ae	800 ± 70Ae	650 ± 70Af
Northern red oak	9,550 ± 1000Aa	3,000 ± 350Bb	3,300 ± 400Bb
Other oak	4,800 ± 500Ab	2,075 ± 180Bc	1,950 ± 200Bd
Pin cherry	1,500 ± 100Ad	1,325 ± 100Ad	0 ± 0Bg
Red maple	10,600 ± 700Aa	5,550 ± 400Ba	2,400 ± 350Cc
Sweet birch	2,900 ± 350Ac	1,650 ± 175Bd	1,450 ± 150Be
Sugar maple	225 ± 125Ad	200 ± 25Af	0 ± 0Bg
Serviceberry	850 ± 50Ae	925 ± 75Ae	725 ± 60Af
Yellow-poplar	385 ± 50Af	1,350 ± 150Bd	1,050 ± 200Be
Miscellaneous	450 ± 50Af	1,350 ± 200Bd	1,150 ± 150Be
Total seedlings	38,035 ± 5000A	25,075 ± 3000B	18,150 ± 2,000C

Table 2.—Stocking (mean proportion of plots ± 1 standard error) of hardwood seedlings by species, treatment, and year. Pretreatment year is 2003 while 2007 and 2010 are after the first and second burns, respectively. Means followed by different uppercase letters are different within that row while those followed by different lowercase letters are different within that year and treatment.

Species or group	2003	2007	2010
	Control treatment		
American beech	6 ± 2Ae	4 ± 1Ag	5 ± 1Af
Black cherry	74 ± 8Ab	78 ± 7Ab	84 ± 8Aa
Cucumber tree	29 ± 2Ac	30 ± 2Ad	32 ± 2Ad
Northern red oak	75 ± 7Ab	61 ± 5Bc	48 ± 7Cc
Other oak	25 ± 2Ac	24 ± 2Ae	17 ± 2Be
Pin cherry	10 ± 1Ad	12 ± 1Af	7 ± 1Bf
Red maple	95 ± 4Aa	94 ± 5Aa	96 ± 3Aa
Sweet birch	72 ± 5Ab	69 ± 3Abc	68 ± 5Ab
Sugar maple	5 ± 1Ae	6 ± 1Ag	8 ± 1Af
Serviceberry	30 ± 3Ac	33 ± 3Ad	35 ± 5Ad
Yellow-poplar	5 ± 1Ae	6 ± 1Ag	3 ±1Ag
Miscellaneous	14 ± 2Ad	18 ± 3Af	15 ± 2Ae
	Spring burn treatment		
American beech	8 ± 1Ae	10 ± 1Ae	11 ± 1Ae
Black cherry	74 ± 8Ab	70 ± 9Aa	69 ± 7Aa
Cucumber tree	26 ± 2Ac	36 ± 5Ac	19 ± 1Bd
Northern red oak	74 ± 7Ab	73 ± 6Aa	74 ± 7Aa
Other oak	29 ± 2ABc	24 ± 2Bd	34 ± 2Ac
Pin cherry	10 ± 2Ae	9 ± 1Ae	0 ± 0Bg
Red maple	96 ± 4Aa	79 ± 9Ba	55 ± 5Cb
Sweet birch	68 ± 8Ab	54 ± 5Bb	51 ± 5Bb
Sugar maple	7 ± 1Ae	3 ± 1Bf	0 ± 0Cg
Serviceberry	32 ± 2Ac	50 ± 5Bb	33 ± 3Ac
Yellow-poplar	7 ± 1Ae	11 ± 1Be	6 ± 1Af
Miscellaneous	18 ± 2Ad	34 ± 2Bc	44 ± 5Cb

Table 3.—Heights (mean feet ± 1 standard error) of the tallest hardwood seedling by species, treatment, and year. Pretreatment year is 2003 while 2007 and 2010 are after the first and second burns, respectively. Means followed by different uppercase letters are different within that row while those followed by different lowercase letters are different within that year and treatment.

Species or group	2003	2007	2010
	Control treatment		
American beech	2.2 ± 2.8Ac	4.4 ± 2.0Ac	5.0 ± 2.8Acd
Black cherry	5.2 ± 2.0Ab	8.7 ± 2.8Ab	8.4 ± 2.0Abc
Cucumber tree	1.5 ± 2.0Ac	2.0 ± 2.0Ad	3.2 ± 2.2Ad
Northern red oak	1.4 ± 2.0Ac	3.1 ± 2.0Ad	2.8 ± 2.0Ad
Other oak	1.5 ± 2.2Ac	2.4 ± 2.3Ad	2.7 ± 2.0Ad
Pin cherry	9.9 ± 2.3Aa	12.9 ± 2.0Aa	17.2 ± 2.3Ba
Red maple	5.1 ± 2.0Ab	10.4 ± 2.0Ba	11.6 ± 2.3Bb
Sweet birch	10.0 ± 2.3Aa	14.9 ± 2.8ABa	18.0 ± 3.5Ba
Sugar maple	2.4 ± 0.5Ac	2.6 ± 0.5Ad	3.3 ± 0.5Ad
Serviceberry	2.3 ± 1.0Ac	3.3 ± 1.1ABd	4.5 ± 1.5Bd
Yellow-poplar	3.6 ± 2.8Abc	5.6 ± 2.5Ac	3.9 ± 2.0Ad
Miscellaneous	2.3 ± 2.3Ac	8.1 ± 3.2Bb	6.5 ± 2.5ABcd
	Spring burn treatment		
American beech	1.8 ± 1.3Ac	2.2 ± 1.2Aa	2.8 ± 1.0Aa
Black cherry	5.7 ± 2.8Abc	3.9 ± 1.4Aa	4.0 ± 2.0Aa
Cucumber tree	1.8 ± 2.0ABc	2.0 ± 0.5Aa	3.2 ± 0.7Ba
Northern red oak	1.3 ± 2.0Ac	2.3 ± 1.3Aa	3.6 ± 1.4Ba
Other oak	1.5 ± 2.0Ac	2.5 ± 1.8ABa	3.3 ± 1.2Ba
Pin cherry	9.7 ± 2.5Ab	2.9 ± 1.0Ba	0.0 ± 0Cb
Red maple	7.2 ± 1.5Ab	4.2 ± 4.0Aa	2.8 ± 3.5Ba
Sweet birch	13.2 ± 2.3Aa	7.0 ± 5.7Ba	3.9 ± 1.5Ca
Sugar maple	1.8 ± 0.2Ac	0.3 ± 0.2Bb	0.0 ± 0Bb
Serviceberry	2.7 ± 1.0Ac	2.6 ± 0.5Ba	2.5 ± 0.6Aa
Yellow-poplar	2.7 ± 1.5Ac	5.6 ± 1.5Aa	2.7 ± 2.0Aa
Miscellaneous	1.5 ± 0.5Ac	2.7 ± 2.0Aa	2.5 ± 1.5Aa

The first spring fire reduced the heights of the tallest seedlings for some species while others had increased height or no change by the third growing season postburn (Table 3). The species with the most height loss were pin cherry, red maple, sweet birch, and sugar maple. Species increasing in height were northern red oak, other oaks, and yellow-poplar while other species did not change in height. Among species, sugar maple was the shortest, 0.3 feet, and all others were taller, ranging from 2.0 feet (cucumber tree) to 7.0 feet (sweet birch). In the control treatment, red maple joined pin cherry and sweet birch in the tallest stratum and yellow-poplar and miscellaneous hardwoods moved into the intermediate stratum.

Three years after the second spring burn, overall seedling densities declined another 28 percent, from 25,075 to 1,8150 seedlings per acre (Table 1). Losses were concentrated in pin cherry and sugar maple (100 percent for each), red maple (57 percent), black cherry (16 percent), and sweet birch (12 percent). Seedling densities for the oaks and other hardwood species were relatively unchanged from the previous inventory. In the control, seedling densities declined another 14 percent, from 31,000 to 26,850 seedlings per acre, with most of this loss occurring with northern red oak (50 percent) and the other oaks (33 percent).

After the second burn, stocking of most hardwood species showed little change from their 2007 levels (Table 2). Three that declined were cucumber tree (36 to 19 percent), red maple (79 to 55 percent), and serviceberry (50 to 33 percent). Conversely, stocking of miscellaneous species increased from 34 to 44 percent. Herbaceous cover remained unchanged from the previous inventory, 50 percent.

Heights among species in the spring burn treatment became quite uniform after the second prescribed fire (Table 3). They ranged from 2.5 feet (serviceberry and miscellaneous species) to 4.0 feet (black cherry and sweet birch) with no differences detected among species. In the control, pin cherry and sweet birch were the tallest at 17.2 and 18.0 feet, respectively, followed by red maple (11.6 feet) and black cherry (8.4 feet). The tallest seedlings of all other species ranged in height from 2.7 feet (other oaks) to 6.5 feet (miscellaneous hardwoods).

DISCUSSION

The upland mixed-oak forests of the ANF epitomize the oak regeneration problem of Pennsylvania and much of the mid-Atlantic region. These forests were born a century ago due to a unique disturbance regime that included multiple harvests, periodic fire, and no deer impact (Marquis et al. 1975). This study intended to test whether that disturbance regime could be recreated by using the shelterwood-burn technique in conjunction with deer fencing. If successful, the ANF would have another tool in its silvicultural toolbox with which to sustainably manage upland mixed-oak forests. Conversely, failure would either eliminate the technique as a viable method or at least expose key caveats important to its successful usage. To date, the results indicate a conditional success; the competitive status of the oak reproduction was improved, but long-term success is not yet assured because of some mitigating circumstances.

Prior to burning, red maple and sweet birch dominated the understory stratum. They made up 35 percent of the seedling population and their seedlings were taller than those of the other species, especially the oaks. This is a common situation in upland mixed-oak forests throughout the region (Albright et al. 2017). Both species can accumulate in the understories of undisturbed oak stands and birch can readily invade during or after regeneration harvests due to its minute wind-blown seeds (Lamson 1990, Walters and Yawney 1990). Harvesting without the concurrent use of prescribed fire exacerbates this situation as demonstrated by the control treatment in this study. At the beginning of the project in 2001, all stands were well on their way to becoming mixed hardwood stands dominated by red maple and sweet birch. Seven years later, this situation had become more pronounced in the unburned blocks as density/stocking of red maple and sweet birch held steady while the heights of their tallest stems doubled. Clearly, harvesting upland mixed-oak stands on the ANF without addressing the aggressive reproduction of red maple and sweet birch will lead to forest type conversion and a loss of the ecologic and economic values contributed by the oaks.

The two spring prescribed fires have stalled, at least temporally, the conversion of the burned portions of these stands to red maple/sweet birch dominance. The burns drastically reorganized the relative composition and dominance of the seedling pool; densities of red maple and sweet birch declined by 77 and 50 percent, respectively. Additionally, their distributions were reduced so they were no longer widespread throughout the burned areas. The two burns eliminated the initial disparity in heights among the hardwood seedlings as the reproduction of all species was between 2.5 and 4.0 feet tall after the second burn. The two fires also evened the relative abundance of the species mix of the regeneration pool. Of the 18,150 seedlings that survived both burns, nearly 30 percent were oak while just 21 percent were red maple and sweet birch.

A large loss of oak seedlings in both treatments occurred throughout the study. In the unburned control, oak seedling densities dropped by 77 percent, from 11,845 to 2,750 stems per acre. In the spring burn treatment, the oak seedling loss was 63 percent, from 14,350 to 5,250 stems per acre. This massive die-off is likely due to a large majority of the seedlings being recent germinants from the fall 2001 bumper acorn crop (Brose 2011, Miller et al. 2017). New oak seedlings are subject to numerous factors that can cause substantial mortality (Brose 2011). In the unburned controls, the oak seedlings likely succumbed to constant dense shade during the growing seasons and periodic browsing by deer. In the prescribed fire blocks, the oak seedlings were just 3 years old at the time of the first burn and had been growing in dense shade their entire lives. They had small roots and such oak seedlings are quite susceptible to being killed by hot spring fires (Miller et al. 2017). Generally, oak reproduction larger than 2 feet tall sprouted postfire, suggesting that they had adequately sized roots to withstand topkilling by fire.

Regarding other hardwood species, reproduction of black cherry, cucumber tree, and serviceberry (three important species with relatively unknown fire ecologies) experienced little mortality, indicating that these species are tolerant of periodic mid-spring prescribed fires. Black cherry is a high-value timber species while all three are important providers of soft mast. Pin cherry and sugar maple seedlings disappeared from the sampling plots after the second burn although they were still present elsewhere in the prescribed fire treatment areas. The loss of pin cherry is surprising given that it is also known as fire cherry (Wendel 1990), a pioneer species that regenerates from buried seed after burning. However, pin cherry is highly desired browse by whitetail deer, and deer incursion into all stands was a chronic problem throughout this study. It is likely that they simply browsed the pin cherry seedlings into oblivion. Also, the salvage cutting and the first prescribed fire may have exhausted the seed bank resulting in few pin cherry germinants after the second burn. The loss of sugar maple was not surprising as this is a species quite sensitive to fire (Godman et al. 1990). American beech, miscellaneous species, and yellow-poplar reproduction increased in densities in the burned areas during the course of the study. For beech, the increase was due to root suckering while the increase in miscellaneous species was driven by proliferation of aspen (*Populus* spp.) and sassafras (*Sassafras albidum*) from root sprouts or buried seed. The increase in yellow-poplar seedlings can be traced to retention of mature trees within the fire treatment blocks that served as seed sources. Finally, fern and grass coverage did not substantially change due to the fire treatments. Apparently, prescribed fire is not a viable approach for controlling these species groups due to their underground rhizomes or soil seedbank longevity (Horsley 1981).

It should be noted that none of these stands had been managed prior to the spring prescribed fires in a manner consistent with the guidelines of the shelterwood-burn technique. In that method, stand stocking is reduced to approximately 50 percent with the cut removing all or nearly all of the midstory stratum (Brose et al. 1999b). Enough overstory trees are removed so that about 50 percent sky is visible. Then 4 to 7 years must pass so that (1) the oak seedlings have sufficient time to develop large enough root systems so their mortality will be minimal; (2) the logging slash can dry and decompose to some degree so that desirable fire intensities can be achieved; (3) leaf litter and other fine fuels can re-accumulate so that the prescribed fire readily spreads; and (4) competing mesophytic hardwood seedlings are beginning to overtop the oak reproduction. In these stands, the midstory was not removed during the harvests and overstory harvesting was based on defoliation-mediated mortality, not creating

50 percent open canopy. Also, the time between the harvests and the first burn was 10 to 15 years. Consequently, the logging slash was quite decomposed likely limiting fire intensities. Additionally, some of the pin cherry, red maple, and sweet birch seedlings had grown large enough to withstand surface fires as well as produce seed. Finally, fence maintenance was lacking; deer intrusion into all the fences was a chronic problem and probably influenced vegetative responses.

In summary, the shelterwood-burn technique appears to be a viable tool for sustaining the upland, mixed-oak forests of the ANF and elsewhere in northern Pennsylvania. The larger oak seedlings readily survive hot, mid-spring prescribed fires and exhibit reasonable height growth postfire. The reproduction of important associate species such as black cherry, cucumber tree, and serviceberry are also strong sprouters postfire. Conversely, sweet birch (the primary undesirable species) is not a strong sprouter, although enough may survive in refugia to facilitate competition problems later in stand development.

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