ASSESSING THE REGENERATION POTENTIAL OF PRODUCTIVE MIXED-HARDWOOD STANDS FOLLOWING SINGLE AND REPEATED PRESCRIBED FIRE

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Abstract—Management efforts on public lands across the southern Appalachian Mountains are increasingly focused on the creation, maintenance, and/or restoration of resilient structures and species compositions, with prescribed burning being the primary tool by which many of these restoration efforts are conducted. In this study, we use regeneration data from a study designed to examine the ecosystem response of upland hardwood forests to prescribed burning in western North Carolina. Four 5-ha productive mixed-hardwood stands were burned between 2009 and 2010. Five years following the first burn (2014), two of the four stands received a second prescribed burn. Regeneration data were collected prior to burning as well as one and five years following the first burn and, for two of the stands, one year following the second burn. Using the REGEN model, we modeled species composition using data obtained from the regeneration inventories to examine how site-preparation burns designed to promote oak seedling development and reduce the abundance of oak competitors may influence post-harvest species composition. Although our results are model forecasts, the underlying data were obtained from actual regeneration inventories. In general, one and two site-preparation burns were forecasted to have little effect on species composition following harvest. The stands used in this study are scheduled to be burned a total of three times prior to implementing a regeneration harvest. Monitoring of the regeneration pool and subsequent success of the various species groups following harvest will be tracked over the long term.

INTRODUCTION

In upland oak-hickory forests of the Central Hardwood Region (CHR), prescribed burning is increasingly used to manage species composition in the forest understory. Objectives associated with burning often include promoting the establishment and development of advance oak reproduction and reducing the abundance of shade-tolerant competitors such as red maple (see app. A for list of scientific names associated with tree species) (Dey and Hartman 2005). The oak regeneration process on intermediate- to high-quality sites, in particular, is complex (Larsen and Johnson 1998), with successful regeneration and recruitment of oak species following overstory disturbance(s) dependent upon the presence of large oak seedlings in the understory prior to disturbance (Sander 1971; Sander 1972; Loftis 1990). Results regarding the efficacy of prescribed fire to promote conditions conducive to the development of competitive advance oak reproduction as well as the ability of prescribed fire to control undesirable, shade-tolerant species are variable (Brose and others 2013; Brose and others 2014). In general, a single burn in closed-canopied, undisturbed oak-hickory forests does little to promote, and in some cases negatively affects, the establishment, growth, and/or abundance of oak reproduction (Brose and others 2013). This has led many to suggest that repeated burning may be necessary to develop competitive oak reproduction and effectively decrease the abundance of shade-tolerant competitors in the forest understory (Albrecht and McCarthy 2006).

Recent reviews of the fire and oak hypothesis (e.g., Brose and others 2014; Brose and others 2013; Arthur and others 2012) suggest the role of fire in sustaining oak forests is complicated, with fire interacting with multiple disturbance agents to affect the oak regeneration process (McEwan and others 2011, Hutchinson and others 2012). Despite growing recognition that prescribed burning alone may not promote the development of competitive oak regeneration across the heterogeneous landscape of CHR (e.g., Iverson and others 2008), burning—either without coupled silvicultural activity (e.g., harvesting) or as a site-preparation tool prior to harvest—continues to be a management tool utilized in mixed-hardwood/

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mixed-oak forests. In this study, we examined the effects of single and repeated prescribed burns on the regeneration potential in productive mixed-hardwood stands in the southern Appalachian Mountains. Specifically, we inventoried the regeneration layer at regular intervals following site-preparation burning and, in conjunction with the regeneration model, REGEN (Loftis 1989), forecasted the effects of single and repeated site-preparation burns on post-harvest species composition.

METHODS

Study site

This study was conducted on the North Carolina Wildlife Resource Commission's Cold Mountain Game Lands (CMGL) in Haywood County, western North Carolina. The CMGL encompasses ~1300 ha and is located in the Blue Ridge physiographic province of the southern Appalachian Mountains. Elevations within the study area range from 975 to 1280 m. Terrain is mountainous with steep slopes. The climate is characterized by warm summers and cool winters. Average monthly temperature ranges from 3 °C in January to 24 °C in July (McNab and Avers 1994). Average annual precipitation approximates 1200 mm and is evenly distributed throughout the year (McNab 2011). In our study, upland oak site index (base age 50) ranged from 23.0 to 30.4 m. Oak (red, white, chestnut, and black oak) and hickory species were the predominant overstory species, whereas sourwood, blackgum, silverbell, flowering dogwood, and red maple dominated the subcanopy positions.

Experimental design and data collection

During the summer of 2008 (prefire), we located four 5-ha mature stands (i.e., the experimental unit) of mixed species composition throughout the CMGL. Within each stand, two transects that ran parallel to the contour were established, with initial transect locations randomly located along the boundary of each stand. The two transects were separated by at least 30 m. Along each of the two transects, three 0.05-ha permanent plots were established at approximately 50, 112, and 175 m along the transects so that each stand contained six 0.05-ha plots—two plots located on each of the lower, middle, and upper slope positions. Within each 0.05-ha permanent plot, we sampled tree regeneration on two 0.004-ha subplots originating 8 m from plot center at bearings of 45° and 225°. Within each subplot, arborescent regeneration sources were tallied by species in the following size classes: (1) <0.6 m tall, (2) 0.6 to <1.2 m tall, (3) ≥1.2 m tall but <3.8 cm diameter at breast height (dbh), and (4) ≥3.8 cm dbh.

On April 1, 2010, two stands (stands 7 and 11) each received a single prescribed burn (hereafter referred to as the 1x burn treatment). Two separate stands (stands 15 and 16) each received two prescribed burns, the first occurring on February 25, 2009, and the second on April 1, 2010 (hereafter referred to as the 2x burn treatment). For all four stands, postfire inventories of the regeneration layer were conducted one and five growing seasons following the first prescribed burn. For stands in the 2x burn treatment, regeneration inventories were also conducted one growing season following the second prescribed burn. All fires were of low intensity and were considered dormant-season fires, as leaf-out had not yet occurred.

Modeling

Using the data collected from the regeneration inventories, we used the REGEN model to examine how site-preparation burns conducted prior to a regeneration harvest may affect post-harvest species composition. In this study, species composition was defined as the percentage of dominant/codominant stems by species group occurring at the time of crown closure following a simulated (i.e., modeled) regeneration harvest. For the 1x burn treatment, we forecasted the effects of site-preparation burning on species composition using the regeneration inventory collected during three time periods: (1) preburn, (2) one year postburn, and (3) five years postburn. For the 2x burn treatment, the effects of site-prep burning prior to harvest on species composition was forecasted using the regeneration data collected during four time periods: (1) preburn, (2) one year following the first burn, (3) five years following the first burn, and (4) one year following the second burn.

The REGEN model is described in depth by Vickers and others (2011). Briefly, REGEN predicts species composition following a stand-replacing disturbance, such as a regeneration harvest, using the following parameters: (1) rankings that quantify the relative competitiveness of various species and possible regeneration sources (i.e, advance reproduction, stump sprouts, root suckers, and new germinants) (table 1); (2) stump sprout probabilities (Keyser and Loftis 2015); and (3) the probabilities of new germinants establishing after harvest. REGEN forecasts species composition by picking six "winners," or species with the highest ranking (i.e., lowest numerical value) on each plot. When a winner is of stump sprout origin, the number of possible winners decreases due to the amount of growing space occupied/required by stump sprouts. Procedures and rules embedded within the model are implemented during situations when regeneration sources of the same rank are chosen as winners. REGEN is operated at the plot level (i.e., winners are selected on each plot) and aggregates plot-level outcomes to produce stand-level estimates of species composition. Low replication (*n*=2 per burn treatment) prevented meaningful statistical analyses. Consequently, we present simple mean values related to post-harvest species composition per treatment.

Table 1—Competitive rankings of regeneration sources found in Appalachian hardwood forests that are submesic in moisture availability and intermediate in elevation and fertility (Loftis 1989)

Rank	Regeneration source
1	Black cherry-SP; Black locust-SP; Sweet birch-SP; Yellow-poplar-SP; Silverbell-SP; Basswood-SP
2	Eastern white pine-L, White ash-SP; Black cherry-L; Red maple-SP; Sugar maple-SP; Sweet birch-L; Yellow-poplar-L; Cucumber tree-SP; Fraser magnolia-SP
3	Black cherry-M; Black locust-L; Sweet birch-M; Yellow-poplar-M; Basswood-L
4	Eastern white pine-M; Hickory-SP; Southern red oak-SP,L; White ash-L; American beech-SP; Black cherry-M; Black locust-M; Chestnut oak-L,SP; Northern red oak-L,SP; Red maple-L; Scarlet oak-L, SP; Sugar maple-L; Sweet birch-S; Blackgum-SP; Yellow-poplar-S; Black oak-SP,L; Sourwood-SP; Silverbell-L; Cucumbertree-L; Hemlock-L; Fraser magnolia-L; Buckeye-SP; Serviceberry-SP; Sassafras-L,SP
5	Hickory-L; Southern red oak-M; White ash-M; American beech-L,RS; Black cherry-S; Black locust-S,RS; Chestnut oak-M; Northern red oak-M; Red maple-M; Scarlet oak-M; Sugar maple-M; Sweet birch-G; White oak-L, SP; Blackgum-L; Dogwood-SP,L; Yellow-poplar-G; Black oak-M; Sourwood-L; Silverbell-M; Cucumbertree-M; Striped maple-SP; Fraser magnolia-M; Buckeye-L; Serviceberry-L; Basswood-M; Ironwood-SP; Musclewood-SP
6	Eastern white pine-S; Hickory-M; American beech-M; Black cherry-G; White oak-M; Blackgum-M; Sourwood-M; Hemlock-M; Holly-L,SP; Striped maple-L; Buckeye-M; Sassafras-M,RS; Ironwood-L; Musclewood-L
7	Southern red oak-S; White ash-S; Chestnut oak-S; Northern red oak-S; Red maple-L; Scarlet oak-S; Sugar maple-S; Dogwood-M; Black oak-L; Silverbell-S; Cucumbertree-S; Holly-M; Striped maple-M; Fraser magnolia-S; Serviceberry-M; Basswood-S; Sassafras-S; Ironwood-M; Musclewood-M
8	Hickory-S; American beech; White oak-S; Blackgum-S; Dogwood-S; Sourwood-S; Hemlock-S; Holly-S; Striped maple-S; Buckeye-S; Serviceberry-S; Ironwood-S; Musclewood-S

SP=Stump sprout (stems ≥3.8 cm diameter at breast height)

L=Large advance reproduction (seedlings ≥1.2 m and <3.8 cm diameter at breast height)

M=Medium advance reproduction (seedlings ≥0.6 m and <1.2 m)

S=Small advance reproduction (seedlings <0.6 m)

G=Germinants that establish after harvest

RS=Root suckers that establish after harvest

RESULTS AND DISCUSSION

The regeneration layer was diverse and abundant prior to and following the burns. Regardless of sampling period and species group, small seedlings, which are less competitive following harvest than larger seedlings and new germinants that establish post-harvest (Loftis 1990) (table 1), dominated the advance reproduction pool in both the 1x (fig. 1) and 2x (fig. 2) burn treatment stands. We observed a lack of any sizeable advance oak reproduction in our study sites; this is characteristic of undisturbed stands throughout the CHR (e.g., Loftis 1983, Loftis and McGee 1993, Iverson and others 2008).

For the 1x burn treatment, regardless of year since burning, canopy species (table 2) were forecasted to dominate species composition following harvest, constituting, on average, 64 percent of the dominant/codominant canopy stems (table 3). Of the canopy species, black cherry—a species capable of regenerating via new seedling establishment—accounted for 52 percent of the post-harvest dominant/codominant stems. In contrast, yellow-poplar, another species capable of regenerating from new seedlings following harvest, remained a minor component of the stand, ranging from 2 to 7 percent of post-harvest

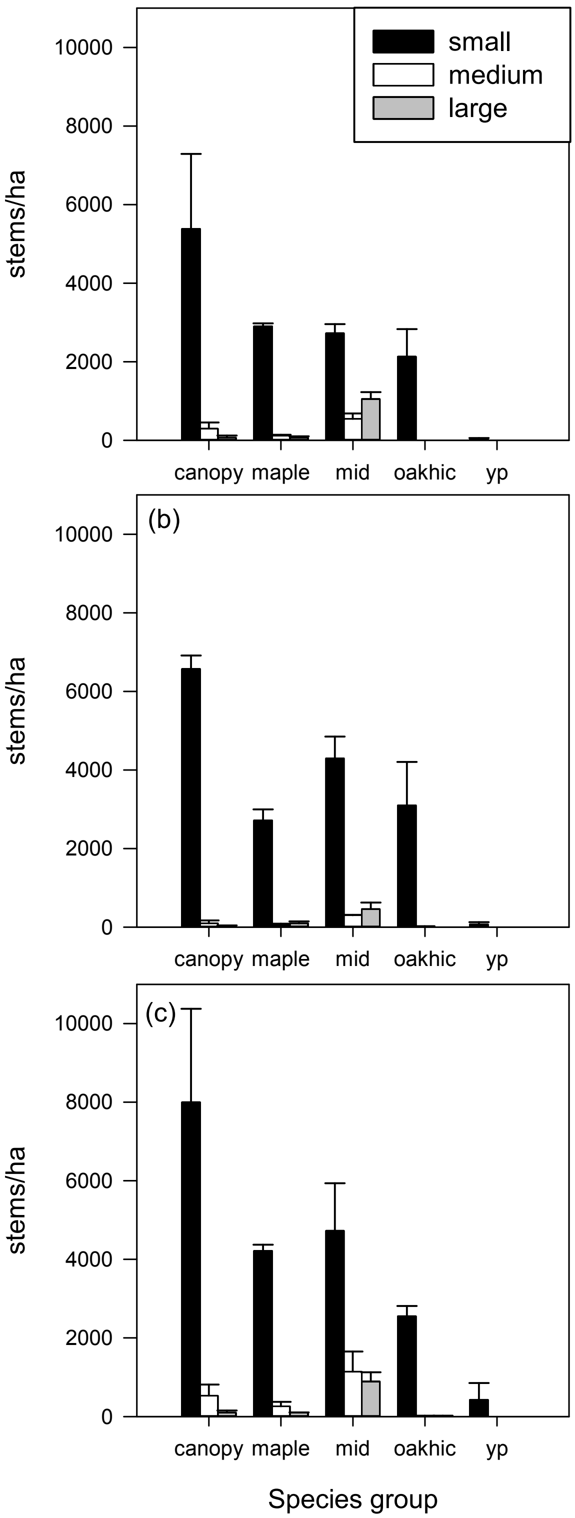

Figure 1—Density of the regeneration layer by species group (table 2) from the 1x burn treatment stands (a) preburn, (b) one year postburn, and (c) five years postburn. Small = advance reproduction <0.6 m, medium = advance reproduction ≥0.6 m and <1.2 m, large = advance reproduction ≥1.2 m and <3.8 cm diameter at breast height. Mid = midstory, oakhic = oak-hickory, yp = yellow-poplar.

species composition. The limited role of yellow-poplar in the post-harvest stand was likely due to these particular stands being located at higher elevations (~1100 m) where forest vegetation begins to transition from upland hardwood forest types to species compositions characteristic of northern hardwood forest types. Regardless of when the regeneration harvest was simulated in relation to time since burn, the contribution of the oak-hickory species group to species composition was predicted to be low (≤2 percent) despite the presence of >2000 seedlings per ha in all regeneration inventories (fig. 1). The lack of the ability of species in the oak-hickory group to compete successfully following harvest was not unexpected, as 99 percent of the oak seedlings were small (<0.6 m) and, consequently, in a noncompetitive position (Sander 1971; Loftis 1990). For maple and midstory species, a single site-preparation burn had little impact on their contribution to species composition following harvest, with maple and midstory species contributing an average of 9 and 20 percent of post-harvest composition, respectively. Although abundant, small maple seedlings, like oak species, were predicted to be unable to compete successfully with faster growing, shade-intolerant species such as black cherry (table 1).

For the 2x burn treatment, the effect of site-preparation burning on the regeneration pool was predicted to increase the amount of yellow-poplar in dominant/codominant positions following harvest (relative to prefire conditions) from 9 to 25 percent (table 4). Unlike the 1x burn treatment, these stands are located at lower elevations where yellow-poplar is abundant and extremely competitive. Relative to other time periods, we observed a 13-percent decrease in the proportion of dominant/codominant oak-hickory stems after harvest when the simulation was conducted one year following the first burn. This is likely due to the 84-percent reduction in large oak seedlings after the first burn (fig. 2). Although the medium and large oak seedling pool experienced a slight recovery, the oak-hickory group was never forecasted to dominate species composition following harvest. Similar to the 1x treatment, little effect of the site-preparation burns on the abundance of species in the midstory group following harvest was observed. For maple, the regeneration pool present one year following the second fire resulted in the lowest proportion of seedlings following harvest, with maple composing 12 percent of the dominant/codominant stems compared to an average of 21 percent over the other three time periods.

Although our results are model forecasts, the data used to conduct model simulations were obtained from regeneration inventories from stands treated with site-preparation burns. Regardless of fire frequency, preharvest site-preparation burning was forecasted to have only minor effects on post-harvest species

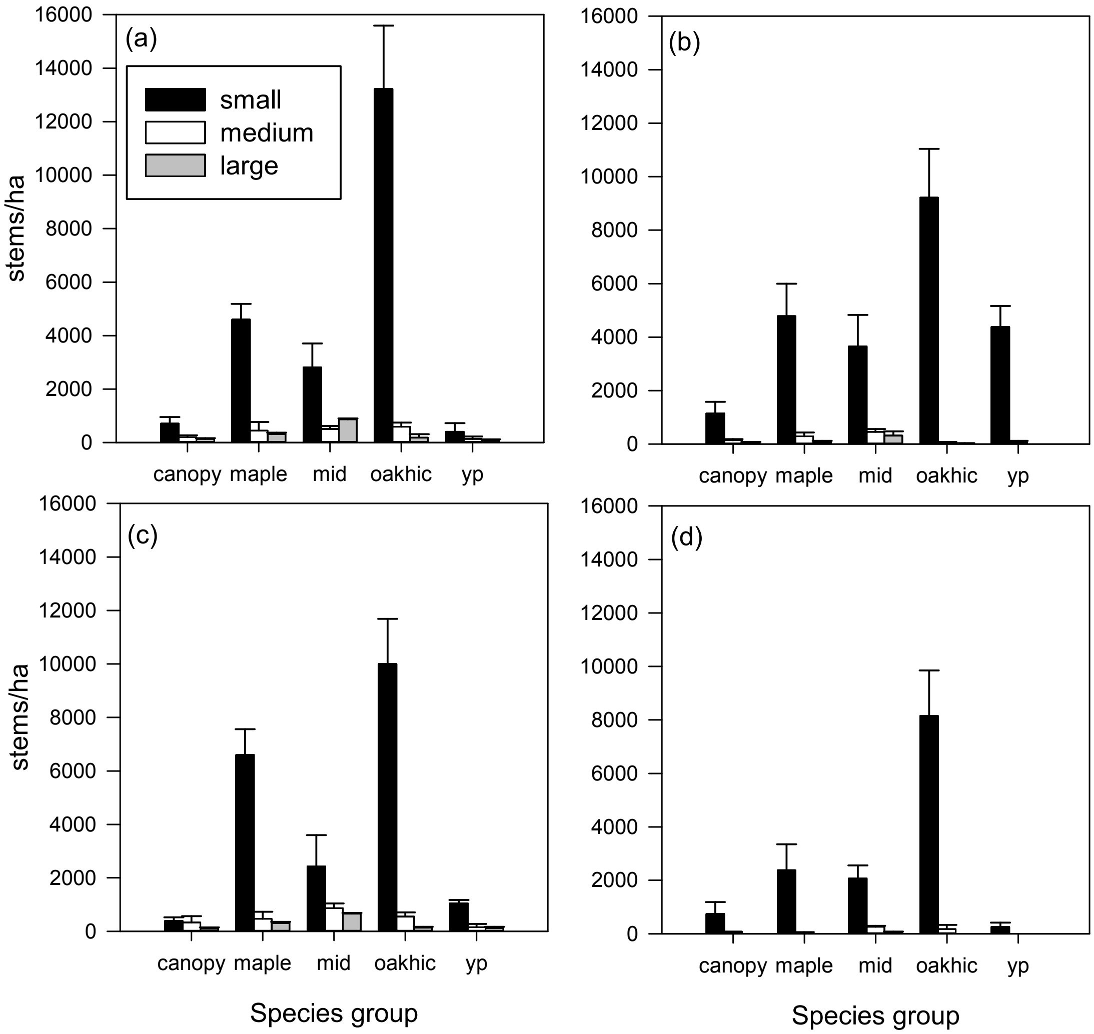

Figure 2—Density of the regeneration layer by species group (table 2) from the 2x burn treatment stands (a) preburn, (b) one year following the first burn, (c) five years following the first burn, and (d) one year following the second burn. Small = advance reproduction <0.6 m, medium = advance reproduction ≥0.6 m and <1.2 m, large = advance reproduction ≥1.2 m and <3.8 cm diameter at breast height. Mid = midstory, oakhic = oak-hickory, yp = yellow-poplar.

composition (table 3, 4). Depending on when the harvest was simulated, site-preparation burns negatively or positively affected oak-hickory abundance in the post-harvest stands; however, overall effects on oak-hickory were minor and likely of little biological significance. From the regeneration inventory data, site-preparation burning was ineffective at recruiting small advance oak-hickory reproduction into larger, more competitive size classes (figs. 1 and 2). In Kentucky, although repeated burns significantly reduced the survival of small red maple seedlings, the competitive status of oak stems remained unchanged due to vegetative resprouting of fire-killed stems and rapid recovery of canopy cover (Alexander and others 2008, Blankenship and Arthur 2006). The limited response of oak-hickory species to burning in this study and elsewhere suggests that burning coupled with some type of canopy removal [and continued competition control via preharvest removal of stump sprout potential (Loftis 1985), continued burning, and/or chemical release treatments] will be required to develop competitive advance oak reproduction and facilitate overstory recruitment (e.g., Hutchinson and others 2012, Arthur and others 2012, Brose 2010; Iverson and others 2008).

MANAGEMENT IMPLICATIONS

Securing oak regeneration is problematic on productive southern Appalachian hardwood forests (Loftis 1990). Therefore, prescribed burning is increasingly used to promote the abundance and competitiveness of advance oak reproduction. Brose and others (2013) suggest site-preparation burning can be used to

Table 2—Species composing species groups

Species group	Species
Canopy	Sweet birch, black cherry, yellow birch, white ash, black locust, black walnut, buckeye, white basswood, Fraser magnolia, Cucumbertree
Maple	Red maple, sugar maple
Midstory	Striped maple, flowering dogwood, alternate dogwood, sourwood, holly, ironwood, musclewood, American beech, silverbell, blackgum, serviceberry, sassafras
Oak-hickory	Hickory species, northern red oak, black oak , scarlet oak, chestnut oak, white oak
Yellow poplar	Yellow poplar
Other	Eastern white pine, shortleaf pine, Virginia pine, pitch pine, eastern hemlock

Table 3—The proportion of the dominant/codominant stems by species group (table 2) forecasted to occur at the time of crown closure by the REGEN model using regeneration inventory data from the 1x burn treatment prior to the fire, one year postburn, and five years postburn. Rounding resulted in some values that sum to <100 percent

Time period	Percentage of dominant/codominant stems					
	Canopy	Maple	Midstory	Oak-hickory	YP	Other
Prefire	65	8	18	2	7	0
One year postfire	64	9	23	2	2	0
Five years postfire	63	10	18	1	7	0

YP = yellow poplar

Table 4—The proportion of the dominant/codominant stems by species group (table 2) forecasted to occur at the time of crown closure by REGEN using regeneration inventory data from the 2x burn treatment prior to the fire, one year following the first fire, five years following the first fire, and one year following the second fire. Rounding resulted in some values that sum to <100 percent

Time period	Percentage of dominant/codominant stems					
	Canopy	Maple	Midstory	Oak-hickory	YP	Other
Prefire	32	25	2	14	25	2
One year after 1st fire	30	18	<1	1	50	0
Five years after 1st fire	29	20	2	10	38	0
One year after 2nd fire	35	12	2	18	34	0

YP = yellow poplar

promote the establishment and competitiveness of oak species prior to harvest. In addition to developing the existing advance reproduction pool, Schuler and others (2010) suggest that site-preparation burning can be used to deplete the seed bank of competitive mesophytic species such as yellow-poplar, sweet birch, and black cherry, a result that contrasts findings specific to our study sites (Keyser and others 2012). Although we report the effects of site-preparation burning on post-harvest species composition after one and two burns, Brose and others (2013) recommend site-preparation burning be conducted up to 10 years prior to harvest if it is to positively affect the abundance of oak and overall species composition in the post-harvest stand. Furthermore, for the most effective competition control, Brose (2010) recommends that burning be conducted during the early growing season, at a time when oak competitors (e.g., maple species) are breaking bud. Burn windows are limited in the southern Appalachians, where precipitation is abundant and evenly distributed throughout the year. Consequently, limiting site-preparation burns to a specific period during the burn season would further reduce the likelihood of accomplishing burns. The stands used in this study are scheduled to be burned a total of three times prior to implementing a regeneration harvest. Monitoring of the regeneration pool and subsequent success of the various species groups following harvest will be tracked over the long term.

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