Managers and Scientists Unite to Adapt a Shelterwood Prescription to Shift Stand Dynamics for Competitive Oak Reproduction

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ABSTRACT.—USDA Forest Service, Southern and Northern Research Station scientists partnered with the Daniel Boone National Forest in Kentucky on a long-term silviculture project focused on enhancing the status of oak in upland hardwood stands under the auspice of the Heathy Forests Restoration Act of 2003. In an attempt to grow small oak natural reproduction into more competitive height classes, we applied herbicide to deaden undesirable midstory trees and to increase sunlight penetrating the forest floor in the first phase of a two-phase shelterwood treatment. We successfully increased the number of larger oak reproduction. However, small red maple stems also responded and are dominating the regeneration cohort. Prior to final harvest, we worked to amend the prescription and to add a preharvest herbicide treatment to target these competitive understory red maple stems. Along the way, many challenges have been addressed, including public education about the need to do applied research on a stand-level basis to discern results prior to recommending prescriptions across landscapes. The value added of having managers and researchers stand together to deliver this message has contributed to the ongoing success of this project.

INTRODUCTION

Three documents came together to make this study and the internal Forest Service partnership between managers on the Daniel Boone National Forest (DBNF) and scientists in the Southern and Northern Research Stations, a reality. The first was the Healthy Forests Restoration Act (HFRA) (Healthy Forests Restoration Act of 2003). This act had two titles (subsections) that were used to develop our program. The first is Title II, which gave authority to obtain information to overcome barriers to production and use of biomass (there was a harvesting and economic facet to this study that will not be covered in this paper). The second is Title IV, which gave authority to develop a program of research to combat infestations by forest damaging insects and diseases with a goal to improve forest health and to reduce forest susceptibility. The second document was the approved Land and Resource Management Plan for the DBNF (hereafter referred to as the Forest Plan) (USDA Forest Service 2004), from which we designed a large-scale, long-term study and wrote a study plan, which became the third document. The study was based solely off of the management detailed in the Forest Plan.

For the DBNF in 2005, the most prevalent damaging insect on the horizon was the gypsy moth (*Lymantria dispar dispar*). The gypsy moth had devastated upland oak (*Quercus*) forests in the northeastern United States, and the forests of the DBNF were certainly at risk for attack (Liebhold et al. 1992). We knew some basics about the gypsy moth: oaks were preferred, particularly those with small or damaged crowns or in subordinate canopy positions (Fajvan and Gottschalk 2012). Also, gypsy moth decline episodes had been documented in oak forests over the past 150 years, and research to address its negative impact on forests had yielded

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some results (Gottschalk 1993, Starkey et al. 1989, Voelker et al. 2008). Although the spread of the gypsy moth has been slowed, it continues to march southward (Tobin et al. 2009).

In the eastern United States, there are abundant oak forests to host the gypsy moth. Approximately 194 million acres of forests are typed as oak, with the most prominent being the oak-hickory (*Quercus-Carya*) type. Oak-hickory forest type dominates the DBNF. So what's up with oak in eastern upland hardwood forests? Essentially, with changes in people demographics, policy, and other social issues, the disturbance regime in these forests has been greatly altered; we have diminished disturbances related to both timber harvesting and fire, as well as removal of many grazing and browsing animals from the forest (Clatterbuck 2019). The loss of the American chestnut (*Castanea dentata* Marsh. [Borkh.]), and the unique disturbance that created, has ceased. We have an age-class shift across all forest types in the east, including oak-hickory, so that 60 to 70 percent of our forests are between 40 and 100 years old (Shifley et al. 2012). These forests are closed canopy and the understories are dominated by more shade-tolerant species than we had in the past (Nowacki and Abrams 2008). All these factors have contributed to the oak regeneration-recruitment problem. We rely on natural reproduction to regenerate our oak forests, and we know that larger oak seedlings and saplings have the best chance of surviving a regeneration event and thus contributing to the composition of the next stand (Sander 1972). The challenge is that we lack large advanced oak reproduction in our stands due to low understory light levels, and we cannot rely on stump sprouts as the larger diameter oaks have a lower probability of sprouting (Weigel et al. 2017).

We have in these forests an "oak bottleneck" (Dey 2014). These forests still have plenty of mature oaks that produce acorns, and germination and establishment are not limiting factors. The challenge is recruiting small oaks into competitive sizes (Dey and Parker 1996, Johnson et al. 1989, Loftis 1990a, Lorimer et al. 1994, Dey and Parker 1996, Sander 1979).

The strategies for this study centered around making our oak forests as healthy and resilient as possible, with an emphasis on the reproduction cohort. The prescriptions we implemented and studied were to (1) increase the component of young oaks; (2) create or enhance oaks in dominant crown positions, which would be less susceptible to mortality following a gypsy moth defoliation event; and (3) increase nonpreferred gypsy moth tree species. For this paper, we are focusing on the oak shelterwood prescription. This has been purported to be one of the most intensive methods to regenerate oak on productive sites where small advanced reproduction exists along with copious competition from other species (Brose et al. 2008, Craig et al. 2014, Hutchinson et al. 2016, Janzen and Hodges 1987, Lockhart et al. 2000, Loftis 1990b, Miller et al. 2017, Parrott et al. 2012, Schweitzer and Dey 2011). The goal of the oak shelterwood is to (1) remove competition in the mid-story to allow small advanced oak reproduction the light needed to develop into a more competitive position; (2) recruit oaks into larger size classes (>5 feet tall) in sufficient numbers; then (3) remove the overstory canopy in a single harvest.

Although we used official authorities and took steps to insure compliance, the public was leery and unhappy. We had a categorical exclusion under the HFRA based on the research component, comments were solicited, and scoping was done. The scoping field trip was a joint adventure by the managers and the scientists. Partly due to public interest, the project was covered by the local press. The Associated Press published an article that led with a sentence about logging (Alford 2005), not about restoration or healthy forests. Others followed suit, including the Cincinnati Enquirer (2005), which was a more robust article and mentioned saving the forest, and The (Louisville, KY) Courier-Journal (Bruggers 2005), which put the DBNF on an "endangered forest" list. Enter the united front of the managers and researchers. Because we were able to show the study plan, the cooperative agreements, and the systematic basis for the study, in conjunction with the Forest Plan, the study went forward (see overview in Schweitzer et al. 2014).

STUDY DESIGN AND AREA

The study was designed as a large-scale, long-term replicated study that used the DBNF Forest Plan as the treatment template. There were five stand-level silvicultural prescriptions or treatments in this study that were a mix of intermediate stand treatments and regeneration treatments (Schweitzer et al. 2014). Here, we concentrate on only one treatment, the oak shelterwood, which was replicated five times.

The Cold Hill Area is located in the Central Escarpment subsection of the Northern Cumberland Plateau Section of the Eastern Broadleaf Forest Province (221 Hb; Bailey 1995). Smalley (1986) described the landtype as the Low Hills Belt association of the mountains and dissected plateau subregion of the Northern Cumberland Plateau. The soils are loamy, formed in residuum weathered from sandstones and conglomerate, and found on broad, flat ridges at elevations of 1000–1250 feet (Smalley 1986). The upland hardwood forests on these sites are predominately sub-xeric types, dominated by oak species, approximately 70 to 100 years old, and have been subjected to repeated disturbances, including selective logging and fire. The six oak shelterwood stands ranged in size from 20 to 30 acres, with an average size of 24 acres. Total basal area (BA) ranged from 100 to 110 square feet per acre, and relative stand density ranged from 60 to 104 percent (Gingrich 1967).

Phase I Oak Shelterwood

We established twenty 0.1-acre vegetation measurement plots in each stand and measured plots before treatment and seven growing seasons after treatment implementation. Plot centers were permanently marked with rebar and global positioning system coordinates were captured for each. We permanently labeled all trees 4.6 inches diameter at breast height (d.b.h.; measured 4.5 feet above ground), measured distance and azimuth to plot center, and recorded species, vigor status, and d.b.h. Within each 0.1-acre plot, we established a 0.01-acre subplot where we enumerated reproduction (trees ≤1.5 inches d.b.h.) by species and 1-foot height class. On these same reproduction subplots, we randomly selected five seedlings that were permanently marked, and species, status, height, and basal diameter were recorded. At 1 year post-treatment, we surveyed status, species, and d.b.h. for all stems ≥1.5 inches d.b.h. on five 0.025-acre plots to access the effectiveness of this treatment in killing midstory stems (1.6 inches d.b.h. to 4.6 inches d.b.h.).

The herbicide treatment was performed using stewardship contracting (Omnibus Consolidated and Emergency Appropriations Act 1999) that allowed the Forest Service to apply the value of timber products removed as an offset against the costs of services received. Undesirable tree species <3 inches d.b.h. were treated with a thinline basal bark treatment using triclopyr ester. Midstory trees >3 inches d.b.h. were treated with a stem injection method using triclopyr amine. The prescription description was to remove non-oak midstory and understory trees without creating any gaps in the overstory to allow increased penetration of ambient light to the oak seedlings in the understory.

RESULTS

Midstory and Overstory Trees

The oak shelterwood stands had 23 species in the midstory and overstory stratum, with 142 stems per acre (SPA) and 99.1 square feet per acre of basal area (BA). Diameters ranged from 4.6 to 33.9 inches. Stem density and basal area were dominated by oaks (black, chestnut, northern red oak, scarlet oak, and white oak; see Table 1 footnote for scientific names of oak species), with 71 SPA and 63.9 square feet per acre BA and a diameter range of 4.6 to 30.9 inches (Table 1). Red maple (*Acer rubrum* L.) densities were 39 SPA with 13.2 square feet per acre BA with diameters 4.6 to 18.5 inches d.b.h., and shortleaf pine (*Pinus echinata* Mill.) had

Table 1.—Overstory and midstory stand structure, including d.b.h. range, stem density (SPA), and basal area (BA), for selected species pretreatment (2009), 1-year post-treatment (2010) and seven growing seasons post-treatment, for stands in the oak shelterwood treatment prescription on the Daniel Boone National Forest, KY

	D.b.h. range	SPA	BA
	inches	*Count per acre*	*ft^2 per acre*
	All species		
2009	4.6-33.9	142	99.1
2010	4.5-34.8	141	105.9
2016	4.2-36.1	91	92
	Quercus spp.[a]		
2009	4.6-30.9	71	63.9
2010	4.7-34.8	70	68.8
2016	4.7.36.1	58	64.4
	Acer rubrum (L.)		
2009	4.6-18.5	39	13.2
2010	4.5-18.9	39	14.5
2016	4.9-19.4	19	11.9
	Oxydendrum aboreum (DC)		
2009	4.7-10.0	10	2.6
2010	4.7-10.5	10	2.7
2016	5.4-11.4	4	1.5
	Carya spp. (Nutt.)		
2009	4.9-22.6	5	3.6
2010	5.1-23.0	5	3.7
2016	5.1-23.9	4	3.0
	Pinus echinata (Mill.)		
2009	11.2-21.7	7	11.6
2010	11.3-22.0	7	11.7
2016	11.6-22.6	2	3.8

[a] Oak species include white oak [*Quercus alba* (L.)], scarlet oak [*Q. coccinea* (Muench.)], chestnut oak [*Q. prinus* (L.)], northern red oak [*Q. rubra* (L.)] and black oak [*Q. velutina* (Lamarck)].

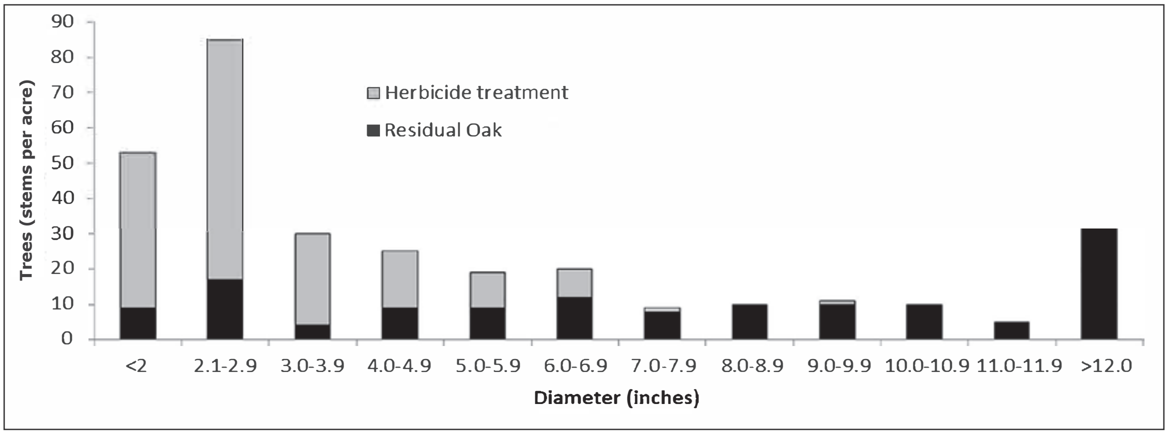

Figure 1.—Stems per acre (SPA) of all tree species, by diameter class, for stems treated with herbicide in Phase I of the oak shelterwood prescription, and the residual stand diameter distribution, Daniel Boone National Forest, KY.

11.6 square feet per acre BA with 7 SPA, and d.b.h. ranged from 11.2 to 21.7 inches. One year post-herbicide treatment, stand structure and composition was relatively unchanged, with total BA at 105.9 square feet per acre, dominated by 68.8 square feet per acre BA of oak, 14.5 square feet per acre BA of red maple and 11.7 square feet per acre BA of shortleaf pine. Across all stands, one tree per acre died of natural causes after 1 year; dead trees were either oaks or red maple.

In the oak shelterwood treatment, we injected with herbicide 176 SPA that averaged 3.0 inches d.b.h. and ranged from 1.6 to 9.1 inches d.b.h. (Fig. 1). Of the stems treated with herbicide, 60 percent were red maple, 7 percent were yellow-poplar (*Liriodendron tulipifera* L.), and the remaining 33 percent were a combination of various species including blackgum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum aboreum* DC), sassafras (*Sassafras albidum* [Nutt.f. Nees.]), bigleaf magnolia (*Magnolia macrophylla* Michx.), and serviceberry (*Amelanchier aborea* [Michx. f. Fern.]).

After seven growing seasons, the midstories and overstories were again dominated by oak, but there was considerably greater mortality, 8 SPA per year. The overall BA was 92 square feet per acre with 91 SPA, dominated by oaks (58 SPA and 64.4 square feet per acre BA) and red maple (19 SPA and 11.9 square feet per acre BA) (Table 1). Mortality was noted in 16 different species, and the greatest mortality was for red maple (three died per year) and for the oaks (two SPA died per year).

Reproduction

All woody species were enumerated in the reproduction survey plots, including small shrubs such as the *Vaccinium* species and *Viburnum* species. Twenty-six woody species were initially identified within the reproduction cohort of stems greater than one foot tall up to 1.5 inches d.b.h., and stem density for all species was 12,687 SPA (Table 2). The pretreatment stem density for red maple was 31 percent of the total reproduction density, while oak constituted 21.5 percent of the total. The largest size class (>4 feet tall up to 1.5 inches d.b.h.) was dominated by red maple and hickory, with only 43 large oaks per acre. Large red maple seedlings were 11 times the density of that of large oak seedlings. Besides red maple and hickory, species with greater densities of large reproduction when compared to oak were viburnum, blackgum, yellow-poplar, flowering dogwood (*Cornus florida* L.), and big leaf magnolia.

Table 2.—Reproduction stems per acres of species by size classes and totals, for pretreatment (pre) and seven growing seasons post-treatment (post), for stands in the oak shelterwood treatment prescription on the Daniel Boone National Forest, Kentucky. Values for oak species are presented in Figure 2. Data presented as ranked highest to lowest for pretreatment density. Row summation may not match Total due to rounding.

Species (authority)	Sample time	<1 ft	>1-2 ft	>2-3 ft	>3-4.5 ft	>4.5 ft-1.5 inch d.b.h.	Total
Acer rubrum (L.)	pre	2187	797	340	140	493	3957
	post	11257	1837	950	477	1377	15897
Quercus spp.	pre	2077	430	147	37	43	2733
	post	2823	763	253	180	163	4183
Vaccinium spp. (L.)	pre	1413	123	7	0	7	1550
	post	1550	690	20	3	3	2267
Carya spp. (Nutt.)	pre	467	263	93	83	120	1027
	post	457	297	160	100	220	1233
Viburnum spp. (L.)	pre	250	130	107	70	63	620
	post	20	33	43	33	23	153
Nyssa sylvatica (Marsh.)	pre	323	113	53	20	63	573
	post	193	130	37	13	80	453
Sassafras albidum (Nutt.) Nees.	pre	330	120	43	13	33	540
	post	167	117	37	37	127	483
Liriodendron tulipifera (L.)	pre	200	47	33	40	67	387
	post	77	27	13	23	117	257
Cornus florida (L.)	pre	230	53	10	10	53	357
	post	203	40	20	17	40	320
Amelanchier arborea (Michx.) Fern.	pre	160	70	37	17	23	307
	post	93	63	47	37	100	340
Magnolia macrophylla (Michx.)	pre	77	33	27	23	63	223
	post	43	10	7	3	53	117
Rhododendron spp.	pre	203	3	0	0	0	207
	post	3	0	0	0	0	3
Oxydendrum aboreum (DC)	pre	13	20	10	3	33	80
	post	3	7	3	10	43	67
Fraxinus spp. (L.)	pre	27	10	3	0	3	43
	post	17	13	3	3	10	47
Ilex decidua (Walt.)	pre	13	10	10	3	3	40
	post	40	17	3	0	20	80
Prunus serotina (Ehrh.)	pre	3	10	0	0	3	17
	post	3	13	0	0	10	27
Fagus grandifolia (Ehrh.)	pre	0	0	7	3	7	17
	post	0	3	0	0	20	23
Castanea dentata (Marsh.) Borkh.	pre	0	0	0	7	0	7
	post	0	3	0	0	10	13
Ostrya virginiana (K. Koch.)	pre	0	0	3	0	0	3
	post	3	0	0	0	0	0
Euonymus spp. (L.)	pre	0	0	0	0	0	0
	post	113	10	10	3	3	140
Tsuga canadensis (L.) Carr.	pre	0	0	0	0	0	0
	post	3	0	0	0	10	13
Diospyros virginiana (L.)	pre	0	0	0	0	0	0
	post	0	0	3	3	0	7
Magnolia acuminata (L.)	pre	0	0	0	0	0	0
	post	0	3	0	0	0	3
Ulmus spp. (L.)	pre	0	0	0	0	0	0
	post	3	0	0	0	0	3
Pinus echinata (Mill.)	pre	0	0	0	0	0	0
	post	3	0	0	0	0	3

Seven years after deadening the midstory, red maple, oak, and hickory all increased in total density (Table 2). Large oak seedlings increased to 163 SPA, and large oak seedling density ranked third behind red maple and hickory. Red maple increased in all size classes, and was 60 percent of all the reproduction stems, while 16 percent was oak. Fifty-seven percent of the largest size class was red maple (a 10 percent increase from pretreatment values), and 6.7 percent was oak (a 3 percent increase). The total density, by species, of viburnum, blackgum, sassafras, yellow-poplar, flowering dogwood, bigleaf magnolia, rhododendron spp., and sourwood all declined compared to pretreatment densities, and the declines were most prominent in the smaller size classes; there was most likely recruitment by many of these species into the open growing space created when the midstory died, and the stem densities in the largest size class for blackgum, sassafras, yellow-poplar, serviceberry, and sourwood all increased.

Of the five oak species tallied in the pretreatment reproduction cohort, scarlet oak was 35.5 percent of the total oak density, followed by white oak (28.9 percent), black oak (21.2 percent), chestnut oak (13.9 percent), and northern red oak (<1 percent). This ranking was the same post-treatment. Within each size class, the density of all five species increased, except for scarlet oak in the largest size (a decrease of 7 SPA) and white oak in the >2- to 3-foot size class (a decline of 47 SPA) (Fig. 2). These white oak stems most likely recruited into the next larger size class, which increased from 7 to 80 SPA. Within each oak species group, the percentage of stems declined for all species for the smallest size class, with a concurrent increase in the percentage in the next three size classes (Fig. 2).

We followed the growth of 150 tagged seedlings, which included 16 different species. Seedlings averaged 3.1 feet in height and had average basal diameters of 0.4 inches. After seven growing seasons, 75 percent of the tagged seedlings were alive, and they were 3.7 feet tall with 0.6 inch basal diameters. Relative height growth was greatest for red maple (1.3 feet), followed by black oak (1.2 feet). The oaks (black, chestnut, scarlet, white, and northern red) averaged 0.6 feet of relative height growth and 0.7 inches of relative basal diameter growth. After seven growing seasons, the oaks and red maple had the same basal diameters (0.5 inches), but red maple absolute height was 2 feet greater (4.8 feet tall) than that for the oaks (2.8 feet tall).

DISCUSSION

Across the Cumberland Plateau, oaks dominate in the overstory, and while oak reproduction exists, it is often lacking in competitive numbers and stature. Although not measured and reported in this study, other studies have shown that reducing the midstory in these types of stands increased the light penetration to the understory, and that light environment was one of the primary drivers of the reproduction cohort response (Dey et al. 2012, Lhotka and Loewenstein 2009, Lorimer et al. 1994, Miller and others 2017, Schweitzer and Dey 2011). After seven growing seasons, we did observe an increase in the number of understory oaks as well as an increase in the size of these oaks. Concurrent with that, however, was a more substantial increase in a major competing species, red maple.

Other studies on similar sites in Kentucky have found that red maple can be competitive with oak in the reproduction cohort, especially after some type of disturbance (Arthur et al. 1997, Lhotka 2012, Tift and Fajvan 1999). In a Kentucky-based study of the response of the understory to treatment of the midstory, Parrott et al. (2012) found dominance by red maple in the larger reproduction size classes. The use of herbicide to reduce the midstory and facilitate increased light to the understory was predicated on studies by Sander (1979), Loftis (1983), and Johnson et al. (1989), in which the directed disturbance via herbicide was to

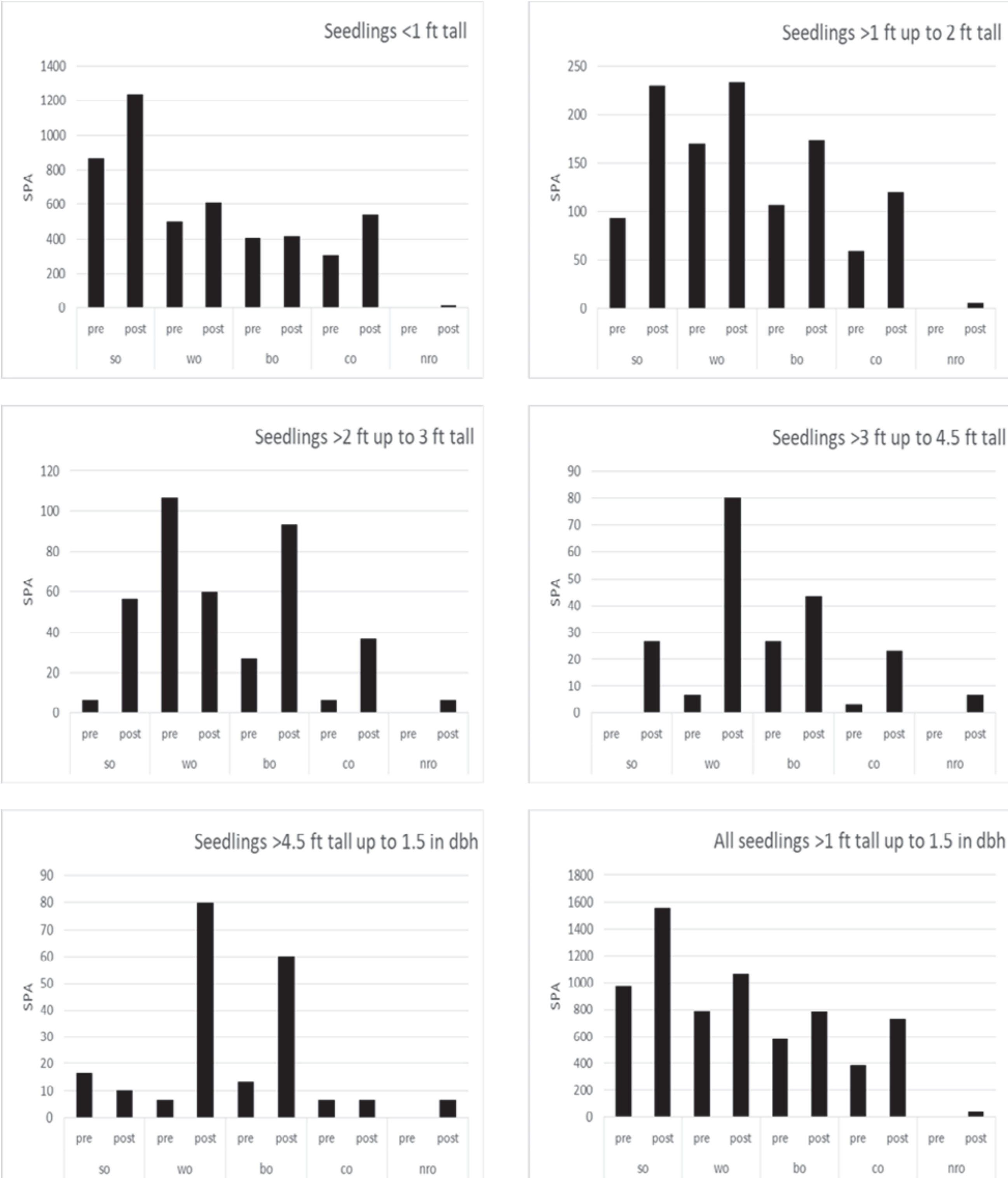

Figure 2.—Reproduction density in stems per acre (SPA) for five oak species for pretreatment (pre) tallies and 7 years post midstory herbicide (post) tallies. Five graphs represents a seedling size class for stands treated with Phase I of an oak shelterwood prescription on the Daniel Boone National Forest, KY. The final graph (lower right) shows a cumulative total of all size classes >1 ft. So= scarlet oak; wo = white oak; bo = black oak; co = chestnut oak; nro = northern red oak. See Table 1 for list of scientific names.

stimulate oak growth over other species. In many initial studies using a midstory herbicide as the first phase in a two-phase shelterwood prescription, results have been mixed (Brose et al. 2008; Craig et al. 2014; Hutchinson et al. 2016; Janzen and Hodges 1987; Schweitzer and Dey 2011, 2017). Differences in site conditions and past disturbance regimes, as well as in current stand structure, age, and composition may be influencing the outcome to a greater extent than predicted. The lack of frequent disturbances may be changing forest conditions that are less favorable to oak regeneration; this lack of management may be causing mesophication toward red maple and other shade tolerant species (Nowacki and Abrams 2008).

We are examining the response of this specialized oak shelterwood prescription at the level of a stand, as delineated by silviculturists and foresters, not at a plot or experimental unit. The range in variation is greater, but through the work in this study, we have learned that implementation at a stand level is not an issue. Contractors and managers worked together to describe and thoroughly execute the midstory herbicide treatment at this scale. Because we were not able to curb the response of the red maple, another treatment will be necessary before the final overstory removal. This treatment will be solely aimed at reducing the density and competitive capacity of the red maple. Discord over the semantics of the next phase notwithstanding, it can be considered a Phase II of the oak shelterwood prescription, with an additional site preparation treatment. This second phase will consist of another treatment using herbicide, followed by the final phase which will be a shelterwood with reserves regeneration harvest leaving 10-15 square feet per acre residual BA.

Preparation for Phase II Oak Shelterwood

Managers and scientists worked together to implement the management and research for this project. The proposal for the Cold Hill Phase II Silvicultural Assessment Project (Phase II Project) was put forth in October of 2017 (USDA Forest Service 2018a) and a field trip was held in November 2017, where managers, scientists, and faculty from the University of Kentucky discussed the current state of knowledge and research and management needs this project was addressing. A final biological assessment and evaluation, needed to address issues related to any potential federally listed endangered species and critical habitat (USDA Forest Service 2018b), was prepared.

The U.S. Fish and Wildlife Service (USFWS) identified 26 federally listed species as potentially occurring on or adjacent to the DBNF (see Table 1, USDA Forest Service 2018b). Twenty-two of these species were determined to be not within the area of influence for Phase II. Four species were analyzed within the biological assessment and evaluation (BAE) and were found to occur or have suitable habitat, or both, within or near the area of influence of the Phase II Project (USDA Forest Service 2018b). These four species—gray bat (*Myotis grisescens*), Indiana bat (*M. sodalis*), Virginia big-eared bat (*Corynorhinus townsendii virginianus*), and northern long-eared bat (*M. septentrionalis*)—were selected for detailed analysis within the BAE. In addition, 43 designated critical habitat segments were identified as occurring on or adjacent to the DBNF by the USFWS, however, none of these segments are located within the area of influence of the Phase II Project.

For the gray bat and Virginia big-eared bat, a determination of "not likely to adversely affect" was given on the basis that gray bat may benefit by the proposed action. The long-term effects of the Phase II Project will provide stands that are more open and have more open corridors while maintaining a supply of suitable roost trees. For the Indiana bat, a determination of "likely to adversely affect" was given based on the fact that some harvest activities are anticipated between April 1 and September 15. The area cut during this period will be monitored and reported by calendar year to ensure compliance with the incidental take statement provided in the USFWS biological opinion (USDI Fish and Wildlife Service 2007). For northern long-eared bat, a determination of "likely to adversely affect" was given based on the effects disclosed in the programmatic biological opinion on implementing the final rule.

A "no impact" statement was given for most of the sensitive species on the basis that all project work is contained within upland, terrestrial areas in stands of timber and do not provide habitat for most of the sensitive species. It was found that the project was consistent with the actions and provisions outlined in the Forest Plan, and consistent with USFWS formal consultation (USFWS 2007, USDA Forest Service 2004). Prior to signing the decision memo in April 2019, managers on the forest noted that this was first time a project involving commercial timber harvesting was able to get through the public comment period without a single negative comment; the partnership with research was touted as a primary reason.

The contract we devised specified using a herbicide in a site preparation treatment for natural regeneration. The goal is to reduce as many sources of red maple competition as possible to allocate growing space to the existing oak seedlings. Specifications and treatment timing followed that of Kochenderfer et al. (2012) and recommendations from consulting forester Christopher Will (pers. comm., Central Kentucky Forest Management Inc., 301 Stanford Ave, Danville, KY 40422; office phone 859-238-2212). All red maple trees within each stand that are 0.5 inches d.b.h. up to 11.9 inches d.b.h. shall receive cut-surface herbicide application treatment with imazapyr (Arsenal® AC herbicide, BASF Chemical Inc., Research Triangle Park, NC). Trees 0.5 inches d.b.h. to 2 inches d.b.h. shall be completely severed using a sharp cutting tool (cut stub treatment) at a point below 3 feet in height from the ground measured from the uphill side of the tree. Herbicide shall be applied at a rate of 1.5 milliliters (ml) (0.05 oz.) of solution per inch of d.b.h. of the tree being treated unless specified otherwise. Hack-and-squirt application will be used to treat trees greater than 2 inches d.b.h. Incisions using hatchets or machetes will be made at a rate of one incision per inch of d.b.h., spaced evenly around the stem with overlapping incisions. Herbicide shall be applied at a rate of 1.5 ml of solution per incision. Incisions shall be made with a downward motion to ensure that herbicide is allowed to enter the incision site when applied from a calibrated spray bottle or other calibrated application device. Treatment will be conducted between the months of August and November. A shelterwood with reserve two-age regeneration harvest will be conducted 1 to 2 years following the herbicide treatment. Residual trees to be retained will be selected based on species and tree vigor, with a goal of 10 to 15 square feet per acreresidual BA.

CONCLUSIONS

Long-term silviculture studies applied at a stand level via partnerships between USFS managers and researchers are essential to driving forest management in a sustained manner. This sustainability is manifested in not only the biological, but also in the social arena. We are able to demonstrate applied, and adaptable, management, under the scrutiny of peer-reviewed science. Because we had detailed data pertaining to the response of the Phase I treatments, we were able to better corroborate technical and scientific quality with the public and others. For this specific oak shelterwood treatment, we will not be able to determine regeneration success until after the parent stand has been removed. Repeated measurements on replicated stands will allow us to discern the specifics of the stand-level responses, and our detailed analyses will aid in providing quantitative descriptions of needed prescription phases to manage these upland hardwood stands across a variety of sites and conditions. The depth and breadth and longevity of this project, as well as its ongoing acceptance and implementation, was made possible through a strong management-research partnership.

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